ISIS

INDIVIDUALIZED SCIENCE INSTRUCTIONAL SYSTEM

PHYSICS OF SPORT

ATE

ISIS

INDIVIDUALIZED SCIENCE INSTRUCTIONAL SYSTEM

PHYSICS OF SPORT

ANNOTATED TEACHER'S EDITION

Ginn and Company

The work presented or reported herein was supported by a grant from the National Science Foundation. However, the opinions expressed herein do not necessarily reflect the position or policy of the National Science Foundation, and no official endorsement by that agency should be inferred.

Ginn and Company
Home Office: Lexington, Massachusetts 02173
0-663-37867-2

ANNOTATED TEACHER'S EDITION

CONTENTS

OVERVIEW

Many people stand in awe of superior athletes and marvel at their natural abilities. While such talents should not be discounted, athletes know that special techniques contribute to true excellence in a sport. These special techniques emerge from close study of how the body can best perform certain tasks. *Physics of Sport* pursues the underlying scientific principles which contribute to superior athletic performance.

This minicourse will not, of course, produce star athletes. But it will allow the student to analyze why certain skills are necessary in a sport, why athletes do things the way they do, and how certain effects are produced.

Physics of Sport has a self-descriptive title. Throughout there is an attempt to meld basic principles of Newtonian physics with their practical uses and consequences in athletics. Statements of physical laws (and elementary formularizations) are interspersed with coaching lore.

Tips on technique, as well as illustrations, are drawn from a wide variety of sports, including baseball, football, basketball, track and field, swimming, tennis, golf, gymnastics, and pool. Student interest should be high.

This minicourse will be useful in either a general science or a physics program.

ORGANIZATION

Physics of Sport contains twelve core activities, four advanced activities, and four excursion activities. The first activity in each section is a planning activity and should be done before any of the other activities in that section. The other activities in each section may be done in any order.

In the core, students analyze several aspects of hitting and throwing: the speed of swing, the angle of release, and the effect of spin on a ball's flight. Another group of core activities looks at collisions, and at force as it relates to direction of motion and leverage. Students also receive practical hints about balance and about the learning of new sports skills.

The advanced activities use simple sports equipment to explore the sophisticated topics of speed and time. Also investigated are energy and momentum measurements during elastic collisions.

Excursion activities build on three topics found in the core. Students can compute their own centers of mass from a few basic measurements. Spin is considered again, this time with respect to projectile stability and postimpact roll. Finally, a simple yet accurate means of determining reaction time is presented.

MATERIALS AND EQUIPMENT

The following tables show the quantity and the frequency of use of each item used in each activity. The activities that require no materials are not listed on the tables.

It is important to collect and organize all the materials for each minicourse before the students begin any of the activities, since the students will be working simultaneously on different activities. Having all materials readily available allows students to do the activities in the order they choose. The amount of material you will need to make available will depend on the number of lab groups that will be doing each activity. As lab groups use the "skipping option" and as they scatter themselves throughout the activities, the total amount of materials needed at one time for each activity will decrease.

CONSUMABLE ITEMS	MINIMUM MATERIALS PER LAB GROUP† PER ACTIVITY								
	4	6	9	10	12	14	18	19	20
Carbon paper, sheet				1					
Card, index, 8 cm X 10 cm	1								
*Cardboard, corrugated, 80 cm X 100 cm (optional)						1			
*Cardboard, corrugated, 20 cm X 20 cm								1	
*Cardboard, heavy, 20 cm to 25 cm square			1						
Chalk, piece					1		1		
Paper, white, sheet, 21.5 cm square		1							
Paper, white, typing				1					
Paper clip			1					1	
String, 30 cm long			1						
String, 50 cm long								1	
String, 120 cm long			1						
Tape, nontransparent, 10 cm									2
Tape, transparent, 30 cm	1								
Towel, paper, 6 each	1								

*See "Advance Preparations."

†A *lab group* is defined as one student, a pair of students, or any size group of students that you choose.

NONCONSUMABLE ITEMS	MINIMUM MATERIALS PER LAB GROUP* PER ACTIVITY														
	3	4	5	6	7	8	9	10	11	12	14	15	18	19	20
Resource Unit 1	1								1	1					1
Resource Unit 2 (optional in Activity 14)									1	1	1				
Resource Unit 4									1	1					
Resource Unit 6								1							
Resource Unit 8		1		1											
Resource Unit 9										1					
Resource Unit 19										1					

*A *lab group* is defined as one student, a pair of students, or any size group of students that you choose.

NONCONSUMABLE ITEMS	MINIMUM MATERIALS PER LAB GROUP† PER ACTIVITY														
	3	4	5	6	7	8	9	10	11	12	14	15	18	19	20
*Angle iron, 5 cm X 30 cm						1			1				1		
*Ball, baseball	1														
*Ball, basketball	1										1				
*Ball, football														1	
*Ball, golf	1											1			
*Ball, handball (optional)	1														
*Ball, soccer (optional)	1										1				
Ball, steel, 15 mm/d (or large marble)				1				1							
Ball, Styrofoam, 8 cm/d			1												
*Ball, table tennis (optional)	1		1												
*Ball, tennis	1							1							
*Ball, volley (optional in Activity 14)	1										1				
*Board, 1" X 12" X 8' (finished)													1		
*Board, 2" X 4" X 18"													1		
*Board, about 2 cm X 30 cm X 45 cm									1						
*Bucket, with tubing attachment		1													
Carpet, piece 60 cm square (or heavy cardboard)									1						
Clothespin, spring type		1													
Eraser, chalkboard										1					
*Medicine dropper (nozzle)		1													
Metre stick	1									1			1		1
Needle or pin							1								
Pencil, wooden, round (or 7 mm/d dowel)				1											
Pin, safety							1								
Protractor (optional in Activity 14)		1		1							1				
Ruler, plastic		1					1								
Ruler, wooden or metal						1									
*Scale, bathroom					1										
Scissors							1							1	
Sponge, rubber, 5 cm square, 0.5 cm to 1.0 cm thick								1							
Stopwatch (or watch with sweep-second hand)									1						
Tray, cafeteria (or other shallow)		1													
*Tubing, rubber, 30 cm long		1													
Washer (or sinker) about 50 g							1								
Weight, about 0.5 kg						1									
Weight, about 1.0 kg (double the other)						1									

*See "Advance Preparations."

†A *lab group* is defined as one student, a pair of students, or any size group of students that you choose.

Since sports equipment is used throughout the minicourse, you may wish to tap your athletic department before the students begin work. Alternatively, you may wish to enlist student aid in assembling the inventory.

For several activities, considerable physical space is required. Anticipating inclement or uncertain weather, you might want to reserve at least a portion of the gym at appropriate times.

ADVANCE PREPARATIONS

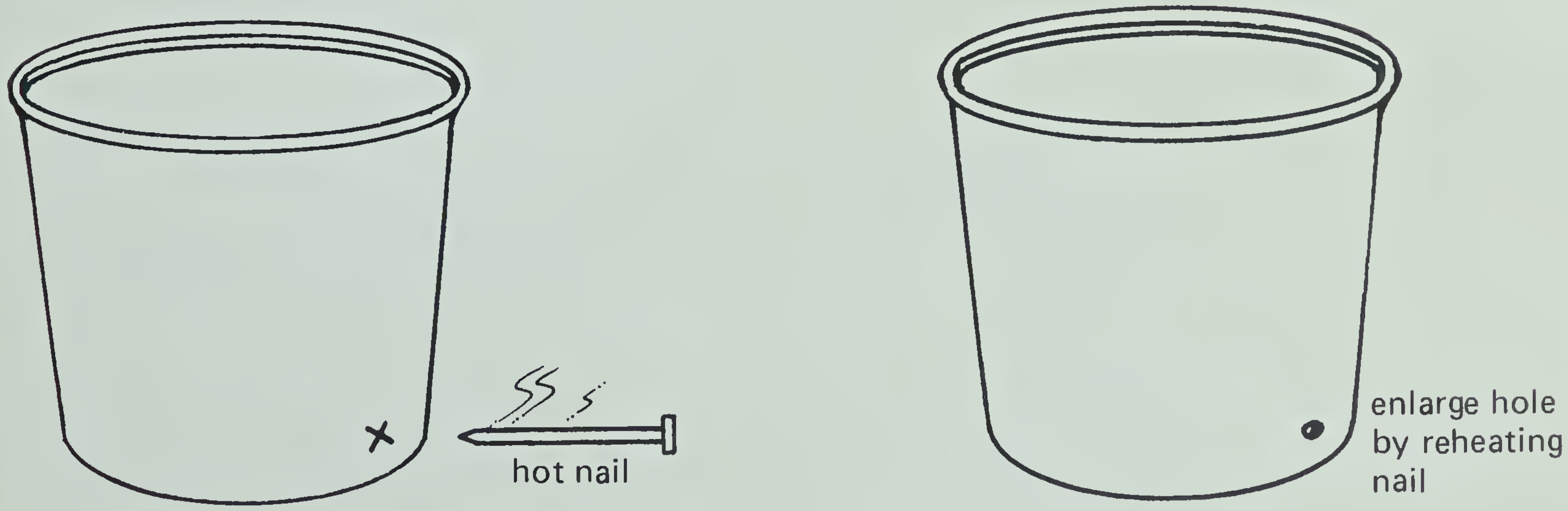
Activity 3

Eight types of spherical balls are listed in the "Materials and Equipment" section. Plan to secure at least five. Substitutions are possible. Just make sure that all balls are round and at least moderately elastic. Some of the balls will be used later (Activities 14, 15, and 19).

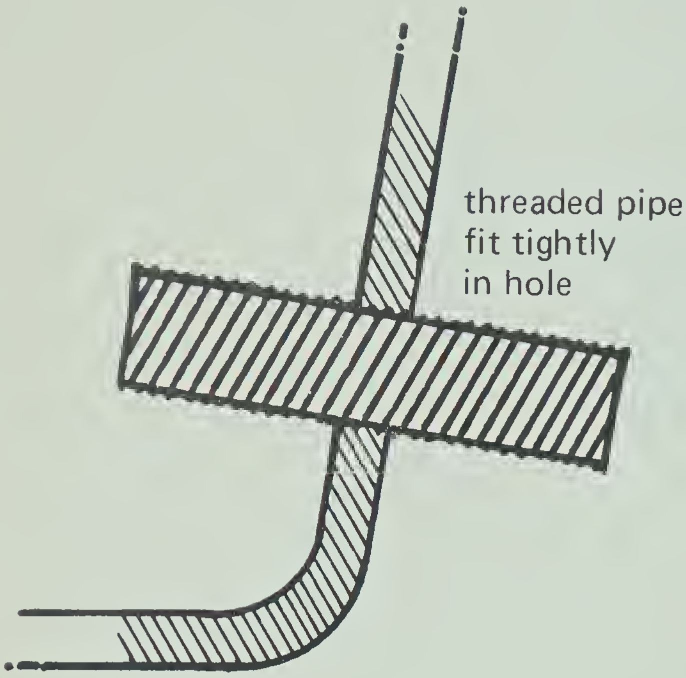
Activity 4

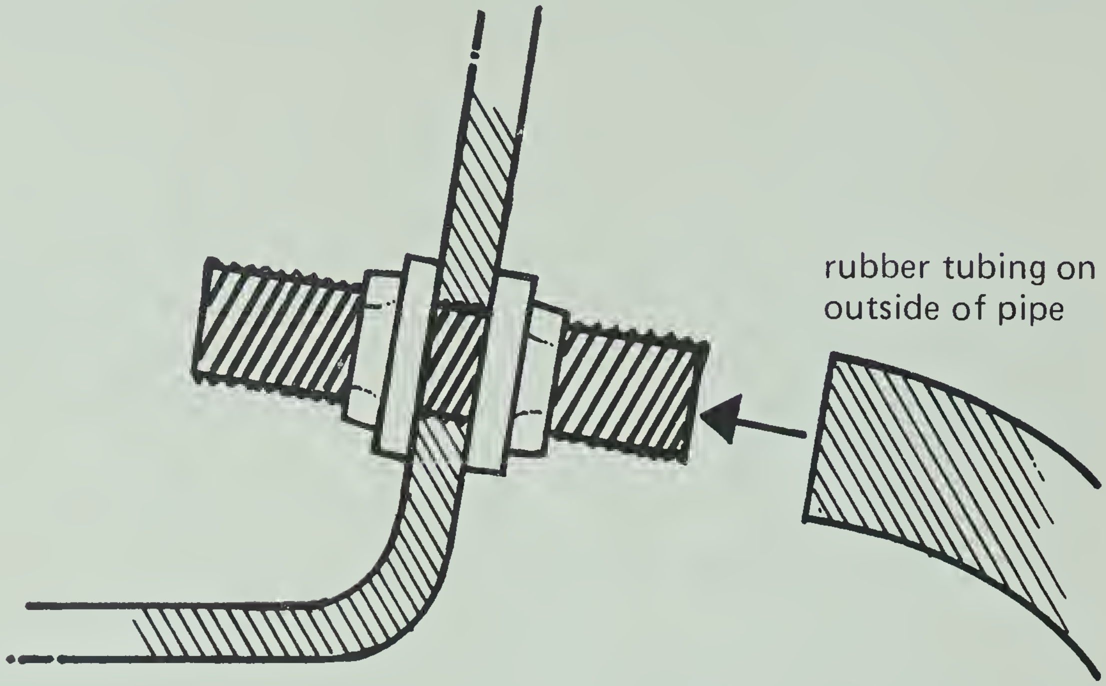
Students need a steady, small stream of water for a trajectory study. You may be able to come up with a simpler way of providing it, but one way is to use a bucket with an attached rubber tubing and medicine dropper.

Heat a large nail and push it through the side of a plastic bucket, about 2 cm from the bottom. Enlarge the hole by reheating the nail. Form a smooth, circular opening just large enough to allow the threaded pipe to be inserted. Smooth around the hole both inside and outside the bucket with a sharp tool or sandpaper.

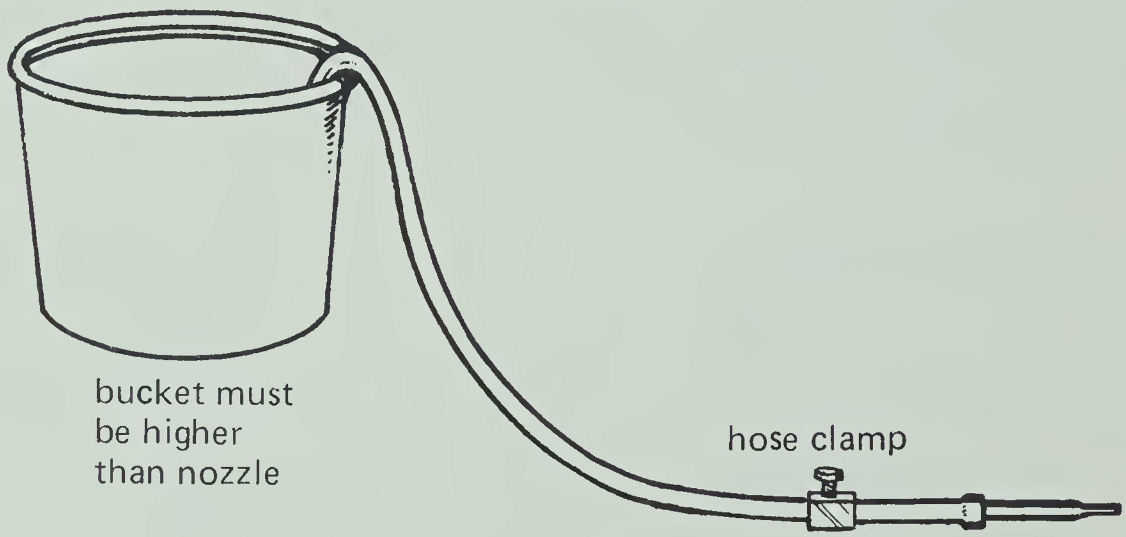


Push the threaded pipe into the hole in the bucket. Put a rubber washer on the pipe, inside and out, and then thread a nut onto the pipe on the inside and on the outside. When the nuts are tightened sufficiently, there should be no leaks. The rubber tubing fits over the outside section of the threaded pipe, with the dropper on the other end.





An alternative setup can be provided by using a siphon. In this case, it would help to use a hose clamp on the rubber tubing so that you can start and stop the stream without losing the siphon. A clothespin with a strong spring might do the job.



Activity 7

The bathroom scale required here can probably be supplied from home by a student.

Activity 9

The cardboard required here can be gotten from the backs of used tablets. You may want to cut the irregular shape ahead of time (you can make several different shapes) or you may want to just make the rectangles of cardboard and scissors available to the students.

Activity 11

The board used here, as well as those in Activity 18, can be borrowed from the school shop or purchased locally.

Activity 19

The cardboard used for the circular disk should be as heavy as possible. The heavier it is, the better the disk will work when spun on the end of the string. You might consider having a 20-cm diameter disk cut from hardboard, plywood, or masonite, with a hole drilled in the center.

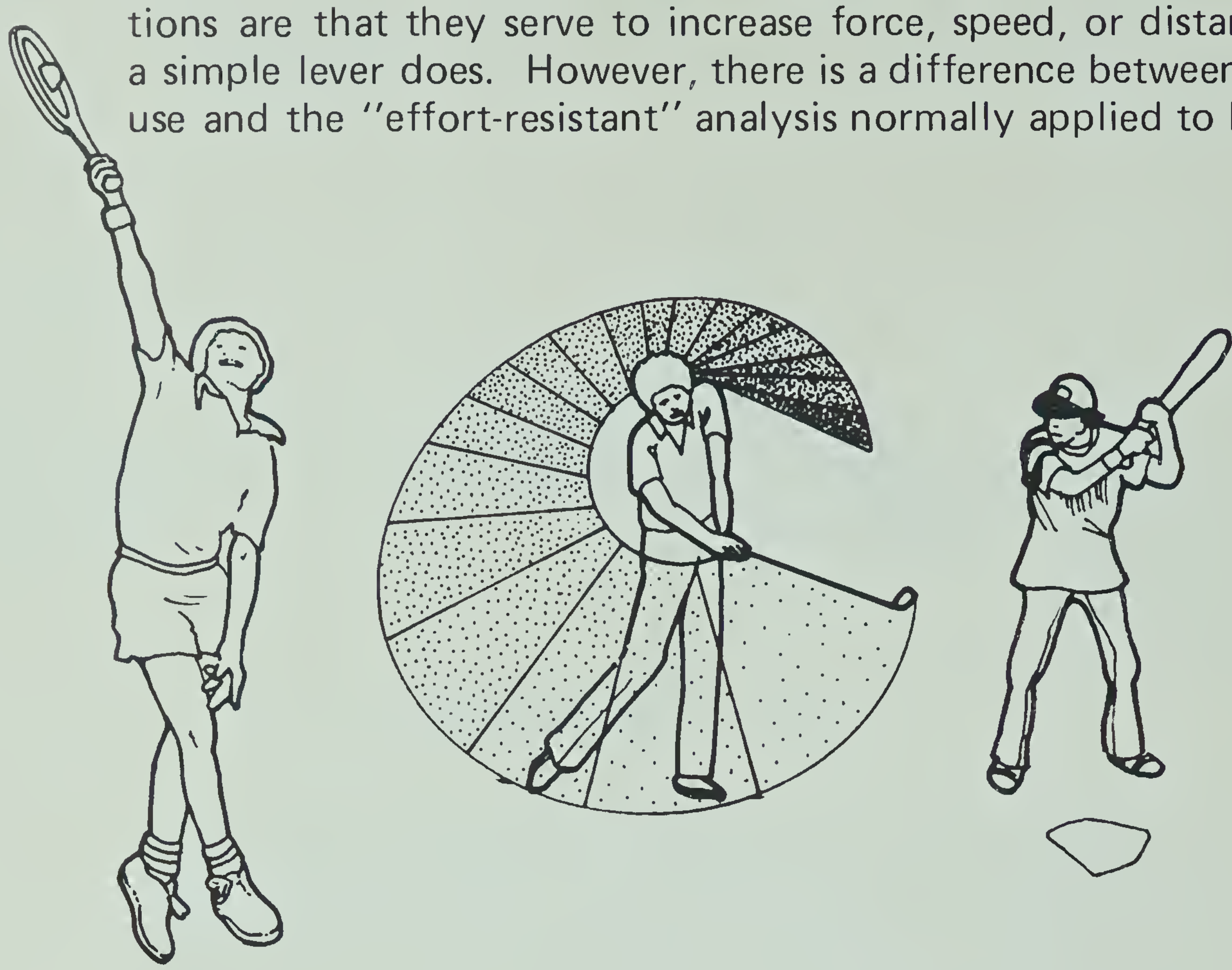
BACKGROUND INFORMATION

General

The structure of the human body, with its bones, muscles, and tendons, is complicated. This presents a problem in attempting to apply the laws of physics to this structure. Various parts of the body are more than simple levers, or force appliers, or energy devices. It would be wise to keep this in mind in the various activities. For example, in Activity 8 an attempt is made to classify the various levers of the body as simply Type 1 (pivot in the middle) or Type 2 (pivot at the end). Actually, in most cases, more than one set of muscles operate and more than one pivot point may be in use. Also the muscles do not all exert their force at a single fixed point. Thus it is difficult to resolve the applied forces into a single force acting at a single point.

Force

Tennis rackets, golf clubs, and baseball bats are treated as extensions of the body's levers on pages 33 and 34. The implications are that they serve to increase force, speed, or distance as a simple lever does. However, there is a difference between their use and the "effort-resistant" analysis normally applied to levers.



In swinging a racket, club, or bat, the major effort is used to accelerate the implement. At the time of striking a ball, a variable force of the ball on the racket, club, or bat is encountered. This force changes the momentum of the ball. The peak value of the changing force can be many times greater than the force exerted by the muscles to accelerate the implement. In part, this is because the time the muscles exerted their force is much greater than the time the ball is in contact with the club. A mathematical analysis of hitting the ball might be something like this:

The *momentum* of the racket club, or bat is equal to its mass (m_i) times its velocity (v_i). This momentum is imparted to the implement by the *impulse* from the muscles, which is equal to the *force* applied (F_m) times the *time* (t_m) through which this force was applied. (The force is assumed to be constant throughout the application.) In equation form

$$F_m \cdot t_m = m_i \cdot v_i$$

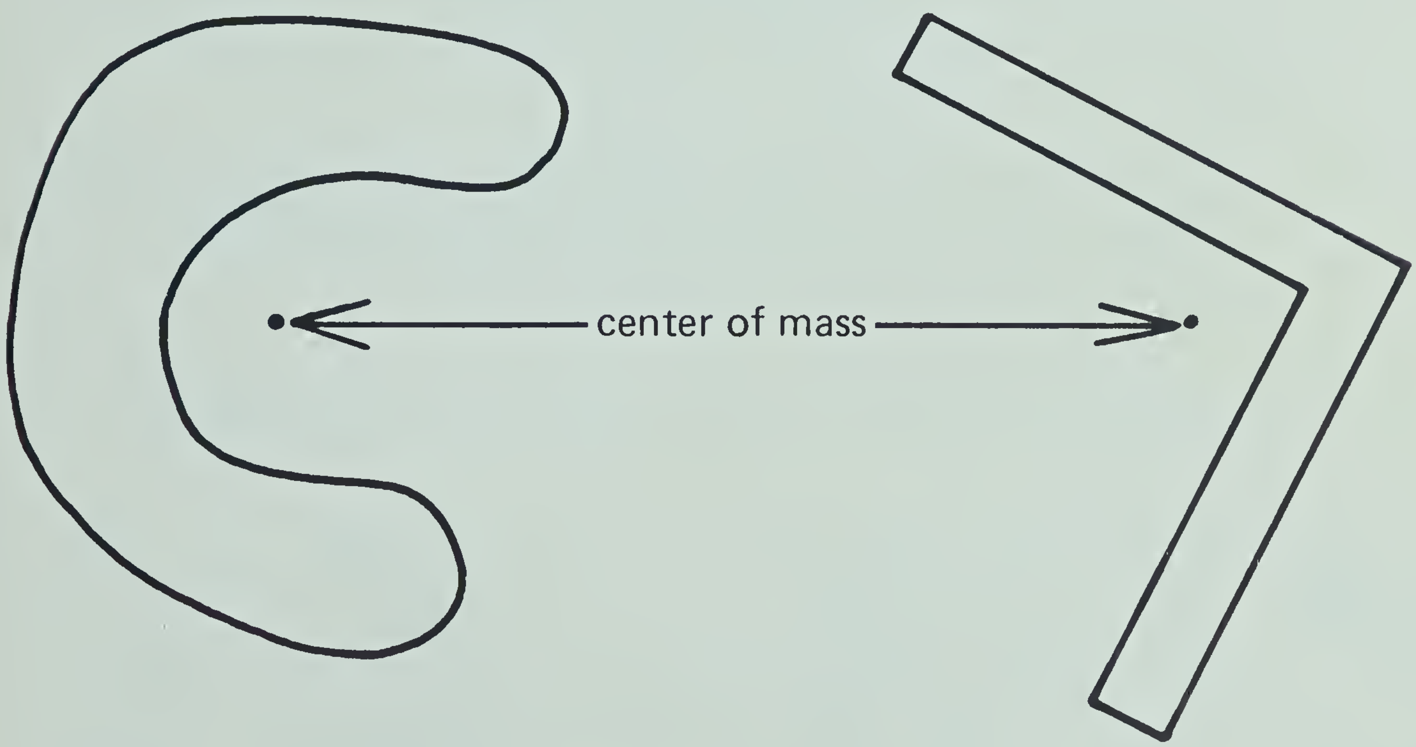
When the racket, club, or bat strikes the ball, some of the implement's momentum is given to the ball. The time (t_b) that the implement exerts a force on the ball is very short compared to t_m, the time that the muscles exerted their force. Striking the ball with a high velocity, the force (F_b) on the ball is high compared to F_m. The impulse $F_b \cdot t_b$ is equal to the change in momentum of the ball, $m_b \cdot v_b$.

$$F_b \cdot t_b = m_b \cdot v_b$$

Center of Mass

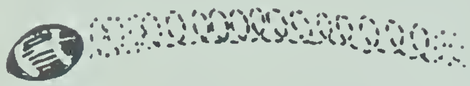
Traditionally, the term "center of gravity" has been used in referring to the point at which a body's "weight" seems to be concentrated. But with the advent of space travel, the more accurate term "center of mass" is increasingly preferred. It is the point at which the body's mass seems to be concentrated.

When you or your students cut out the irregular shaped cardboard pieces for Activity 9, it is possible to cut one so that the center of mass falls outside the body (see below). If this happens, an interesting question for the better student might be, "How could you check the point by the balancing method to see if it really is the center of mass?"



Spin Stability

In Activity 19, a disk is swung on the end of a string. The student finds that when the disk is spinning rapidly, it exhibits marked stability in that it does not tumble, but tends to keep its axis in the same direction. In doing this, it behaves as a gyroscope. One of the operating principles of a gyroscope is rigidity in the plane of rotation. This same principle is used to stabilize ocean liners to keep them from rolling in rough seas. It is also used in the gyroscopic compass, where the spinning gyroscope remains rigid in its rotational plane while the vehicle, be it a sea vessel or aeroplane, turns around it. Of course, in sports it is important because a spinning projecticle follows a more regular course.



EVALUATION SUGGESTIONS

In addition to the *Minicourse Test*, answers to which are provided with the test, you may want to use the following essay questions.

Essay Questions

Three essay questions are included here with model answers for your convenience. Each essay suggestion relates to material found in core activities.

1. Suppose that you are playing tennis (or golf). Briefly describe how each of the following situations can affect your game.
A. Use of a light racket (or club)
B. Playing on a cold day
C. Applying backspin to a shot
D. Gripping the racket (or club) at the very end of the handle

Answer:
A. A fast swing or stroke will be needed to give the ball greater speed.
B. A tennis ball loses a lot of elasticity in cold weather, so it will travel more slowly off the racket and will not bounce as high. A golf ball is not affected by cold weather as much.
C. Compared to its normal action, the ball will stay in the air longer and will tend to stop sooner when it lands.
D. With the racket (or club) acting as a lever, gripping the very end produces maximum swing speed.

2. Suppose you want to design a program to train your classmates to be football linemen. Explain why each of the following is a needed part of your training program.

A. Assuming a low, crouching position

B. Using the shoulder or body to block or tackle rather than just using the hands

C. Practicing two or three skills each day of training, rather than just one skill for a whole practice

D. (For some players) trying a position other than lineman

Answer:

A. More stability and maneuverability is maintained if the base of support is wide and the center of mass is close to the ground.

B. A larger body area more easily absorbs the force of contact.

C. Spaced practice usually results in more improvement than massed practice.

D. Not all players have the same physical abilities, and therefore some cannot perform these skills as well as others can.

3. The direction in which you apply a force is important in sports. What do you need to know about force direction in order to do each of the following successfully?

A. Put a shot the maximum distance

B. Bank a pool ball off a cushion accurately

C. Get off to the fastest start in a footrace

Answer [Answers are theoretical and assume zero spin and air resistance, and (in the case of the pool ball) perfect elasticity. Performance under actual conditions can lead to different results.]:

A. Putting the shot at a 45° angle produces the greatest distance.

B. On a bank shot in pool, the angle of rebound is equal to the incoming angle.

C. When running, you should be pushing forward with your legs rather than upward.

REFERENCES

Councilman, J.E. *The Science of Swimming.* Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1968.

The first chapter, "Mechanical Principles Involved in Swimming," has a discussion of resistance, inertia, and reaction that can be applied beyond the topic of swimming. The book is well illustrated.

Daish, C.B. *Learn Science Through Ball Games.* New York: Sterling Publishing Co., 1972.

Daish gives clear and succinct explanations. Although the reading level is comparable to that of the advanced activities, many sections are appropriate for all students.

Dyson, Geoffrey. *The Mechanics of Athletics.* 6th ed. London: University of London Press, 1973.

Dyson's paperback treats the topics of motion, force, and angular motion with particular reference to track and field events. Clear illustrations abound.

The following books are college-level texts suggested as background for the teacher. Perhaps the athletic staff at your school has similar materials at a reading level more suitable for your students.

Hay, James G. *The Biomechanics of Sports Techniques.* Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1973.

This is a well-illustrated application of the principles of motion, center of mass, and vector analysis.

Northrup, John W., Logan, Gene A., and McKinney, Wayne C. *Introduction to Biomechanic Analysis of Sport.* Dubuque, Iowa: Wm. C. Brown Co., 1974.

The physics of sport is explained, following good introductions to human anatomy and human motion analysis.

Wells, Katharine F. and Kathryn Luttgens. *Kinesiology: scientific basis of human motion.* Philadelphia: Saunders, 1976.

ISIS

INDIVIDUALIZED SCIENCE INSTRUCTIONAL SYSTEM

PHYSICS OF SPORT

Ginn and Company

acknowledgments

In addition to the major effort by the ISIS permanent staff, writing conference participants, and author-consultants (listed on the inside of the back cover), the following contributed to this minicourse.

Art created by: ISIS Staff

Cover designed by: Clementi Studios

Special Consultant: Clifton Bob Clark, Professor of Physics, The University of North Carolina at Greensboro, Greensboro, North Carolina

The work presented or reported herein was supported by a grant from the National Science Foundation. However, the opinions expressed herein do not necessarily reflect the position or policy of the National Science Foundation, and no official endorsement by that agency should be inferred.

Ginn and Company
Home Office: Lexington, Massachusetts 02173
~~0-663-37861-3~~
0-663-37867-2

Foreword

Evidence has been mounting that something is missing from secondary science teaching. More and more, students are rejecting science courses and turning to subjects that they consider to be more practical or significant. Numerous high school science teachers have concluded that what they are now teaching is appropriate for only a limited number of their students.

As their concern has mounted, many science teachers have tried to find instructional materials that encompass more appropriate content and that allow them to work individually with students who have different needs and talents. For the most part, this search has been frustrating because presently such materials are difficult, if not impossible, to find.

The Individualized Science Instructional System (ISIS) project was organized to produce an alternative for those teachers who are dissatisfied with current secondary science textbooks. Consequently, the content of the ISIS materials is unconventional as is the individualized teaching method that is built into them. In contrast with many current science texts which aim to "cover science," ISIS has tried to be selective and to limit our coverage to the topics that we judge will be most useful to today's students.

Obviously the needs and problems of individual schools and students vary widely. To accommodate the differences, ISIS decided against producing tightly structured, pre-sequenced textbooks. Instead, we are generating short, self-contained modules that cover a wide range of topics. The modules can be clustered into many types of courses, and we hope that teachers and administrators will uhilize this flexibility to tailor-make curricula that are responsive to local needs and conditions.

ISIS is a cooperative effort involving many individuals and agencies. More than 75 scientists and educators have helped to generate the materials, and hundreds of teachers and thousands of students have been involved in the project's nationwide testing program. All of the ISIS endeavors have been supported by generous grants from the National Science Foundation. We hope that ISIS users will conclude that these large investments of time, money, and effort have been worthwhile.

Ernest Burkman

Ernest Burkman
ISIS Project
Tallahassee, Florida

CONTENTS PAGE

WHAT'S IT ALL ABOUT?

Thrown baseballs really can curve, and in this minicourse science tells you why. It shows you how long jumpers get more distance and swimmers get more speed. Science can help you understand how gymnasts keep their balance and how basketball players improve their foul-shooting percentage. And there's lots more. This minicourse won't make you a top athlete, but it can help you to enjoy better the sports you watch or play.

CORE

ACTIVITY 1: PLANNING

Activity 2 — Page 2

Objective 2-1: Describe how bat weight and bat speed affect the speed and distance a ball will travel.

Sample Question: Which of the following is more important to make a baseball go fastest when hit with a bat?

A. Bat weight
B. Bat speed
C. Both equally
D. Neither

Activity 3 — Page 6

Objective 3-1: Relate elasticity to the distance a hit ball travels.

Sample Question: Two similar balls are hit with the same force. Their distances of travel are measured. Ball A traveled farther than Ball B. Which has the greater elasticity, A or B?

Activity 4 — Page 9

Objective 4-1: Tell how the angle of projection and the distance through which a force is applied influence the distance a ball will travel.

Sample Question: In order to achieve maximum distance, what is the best angle of release?

A. 45°
B. 35°
C. 55°
D. 90°

Activity 5 — Page 13

Objective 5-1: Tell how spin influences the flight of a ball in air.

Sample Question: A ball with backspin will tend to do which of the follwing as it travels through the air?

A. Drop
B. Rise
C. Curve right
D. Curve left

Activity 6 — Page 17

Objective 6-1: Predict the direction a ball will travel when it rebounds from a surface.

Sample Question: When a nonspinning ball bounces off a flat surface, the outgoing angle is

A. equal to the incoming angle.
B. one half of the incoming angle.
C. twice the incoming angle.
D. unpredictable.

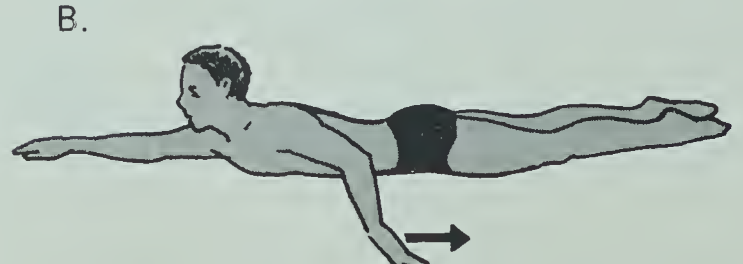
Activity 7 — Page 23

Objective 7-1: Identify the correct direction in which to apply force to improve a person's running or swimming speed.

Sample Question: Which of the following two pictures shows the correct direction to apply arm force during swimming?

A.

B.



Activity 8 — Page 27

Objective 8-1: Tell how levers are used in sports to improve performance.

Sample Question: Which two things are advantages of levers?

A. Increased speed
B. Increased force
C. Increased skill
D. Increased mass

Activity 9 — Page 35

Objective 9-1: Tell how the size of the base of support and the height of the center of mass affects a person's stability.

Sample Question: In which of these positions is a football player most stable (least likely to be knocked off balance)?

A.

B.

C.

Activity 10 — Page 42

Objective 10-1: Identify two factors to slow or stop a moving person or ball successfully.

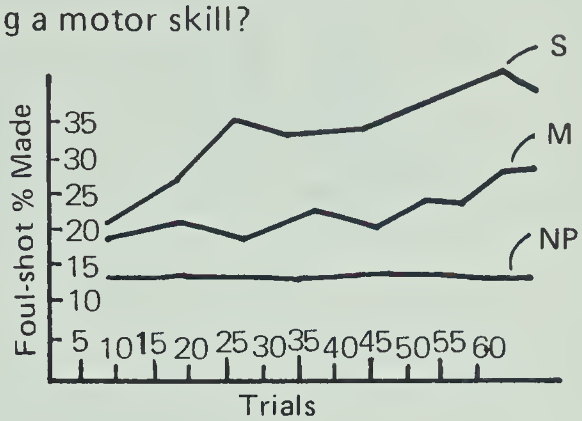
Sample Question: What are two things you can do to increase your chances of catching a ball successfully?

A. Use two hands.
B. Use closed hands.
C. Hold your arms stiff.
D. "Give" with the ball.

Activity 11 — Page 47

Objective 11-1: Identify general trends shown by graphs.

Sample Question: According to the graph below, which method of practice resulted in the most rapid rate of learning a motor skill?



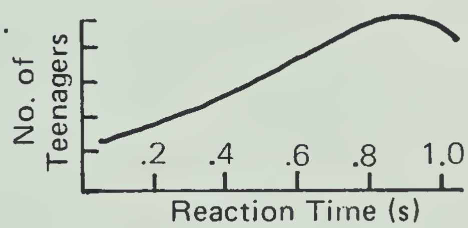
A. Massed (M)
B. Spaced (S)
C. No practice (NP)
D. A combination of massed and spaced

Activity 12 — Page 52

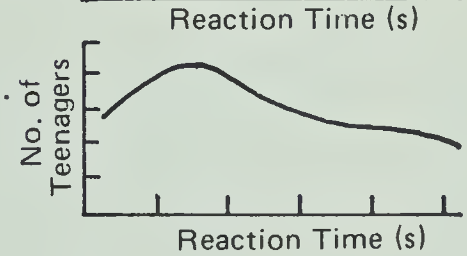
Objective 12-1: Tell how motor (sports) abilities vary among teenagers.

Sample Question: Which graph has a curve that shows the distribution of reactions times among teenagers?

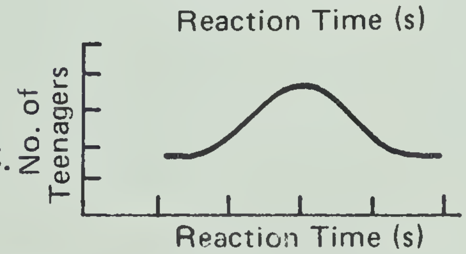
A.



B.

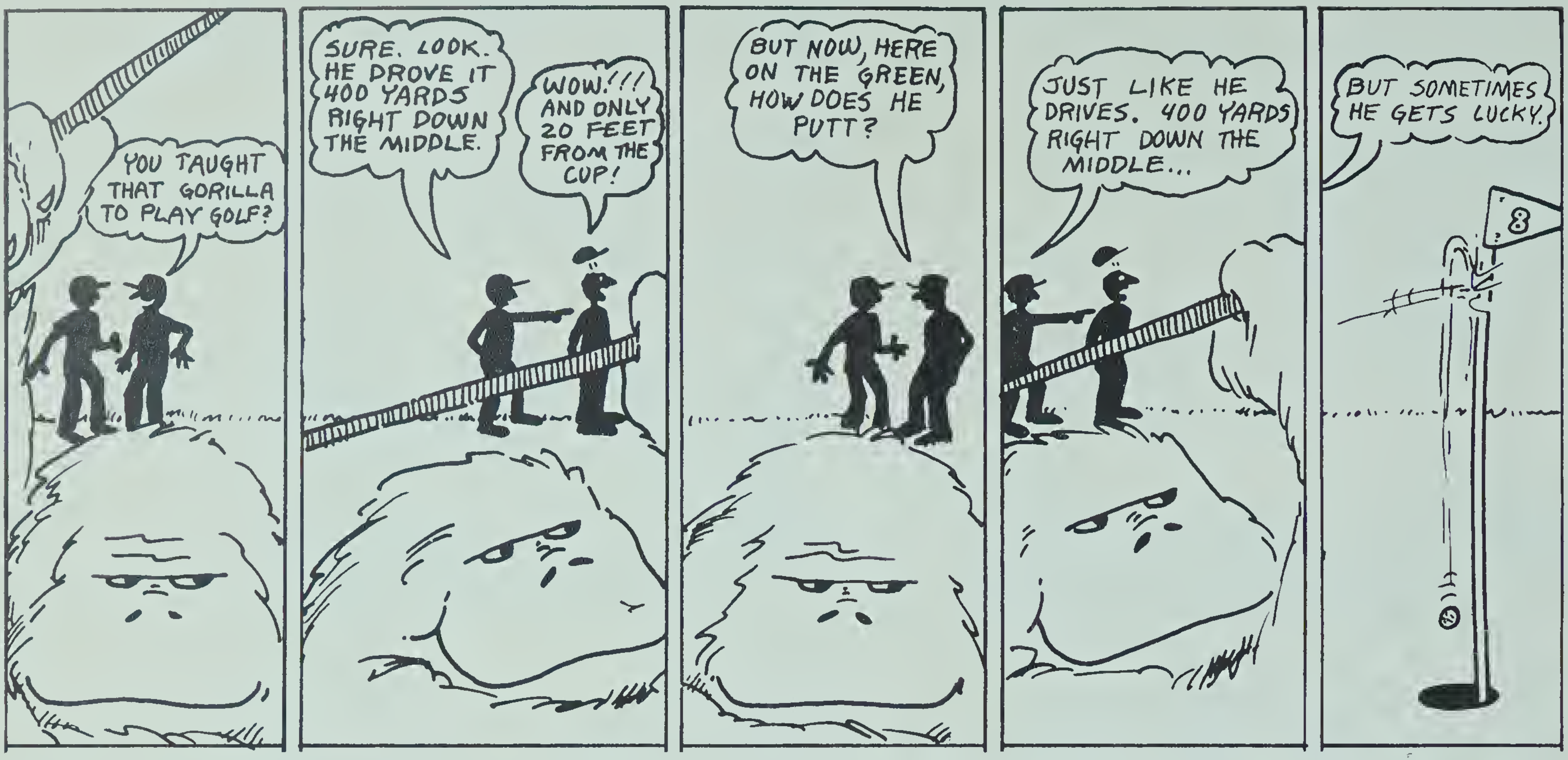


C.



Answers: **2-1.** B; **3-1.** A; **4-1.** A; **5-1.** B; **6-1.** A; **7-1.** B; **8-1.** A, B; **9-1.** B; **10-1.** A, D; **11-1.** B; **12-1.** C

ACTIVITY 2: SELECTING YOUR BAT



ACTIVITY EMPHASIS: Bat weight and bat speed are both important in hitting for distance, but speed is the more important.

MATERIALS PER STUDENT LAB GROUP: None

Official rules of baseball limit diameter of bat to 2 3/4″ (7 cm), and length of bat to 42″ (107 cm), but there is no official limit on bat weight.

2-1. A ball should travel faster and thus farther when hit with a heavier bat.

As the cartoon above shows, hitting for distance isn't everything. Bunts in baseball and lob shots in tennis are other examples of balls you want to hit softly. But suppose distance is your goal. Suppose you are going for the home run or the big drive or the service ace. What factors do you need to consider?

One such factor is *bat* or *club weight*. In sports like baseball you usually have a wide choice of what to use. Some players use heavy bats or clubs, while others use light ones. Does weight make any difference?

Look at Figure 2-1 below. It shows what happened to the speed of a hit baseball when one particular player used different weight bats. Everything else was kept the same each time — the ball, the speed of the pitch, and the speed of the bat.

WEIGHT OF BAT	SPEED OF BALL AFTER HIT (in metres/sec)
0.57 kg (20 oz)	30.6
0.71 kg (25 oz)	32.6
0.85 kg (30 oz)	34.0
0.99 kg (35 oz)	35.1
1.14 kg (40 oz)	35.9

Figure 2-1

- 2-1. From Figure 2-1 above, what can you say about the influence of bat weight on the distance a hit baseball will travel?

Hitting a baseball hard depends on more than the weight of the bat. Another important factor is how fast the bat is swung. Look at Figure 2-2 below. Here the player used a 0.85 kg bat each time but varied the speed of his swing.

SPEED BAT WAS SWUNG (in metres/sec)	SPEED OF BALL AFTER HIT (in metres/sec)
9.2	27.7
12.2	30.7
15.3	34.0
18.3	37.4
21.4	40.8

Figure 2-2

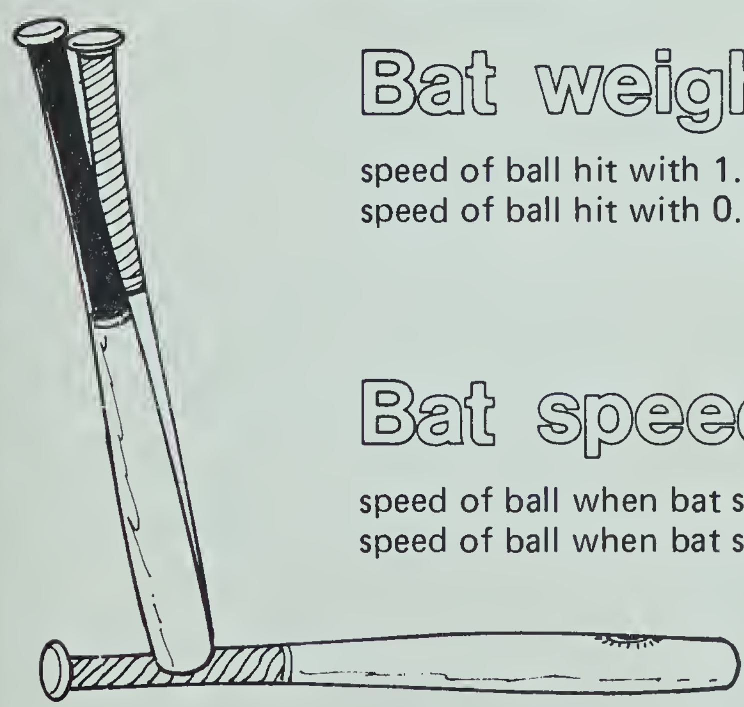
• 2-2. Using the information in Figure 2-2 above, what can you say about the effect of bat speed on the distance a hit ball will travel?

2-2. A ball should travel farther when hit with a bat traveling at a faster speed

• 2-3. What two factors affect the speed of a hit baseball and the distance it will travel?

2-3. Bat weight and bat speed

The statistics quoted show that this particular player could hit a ball harder by *either* using a heavier bat *or* swinging harder. But were these two factors equally important? You can find out by making some simple calculations.



Bat weight

speed of ball hit with 1.14 kg bat: 35.9
speed of ball hit with 0.57 kg bat: 30.6
Difference 5.3 m/s

Bat speed

speed of ball when bat swing 18.3 m/s: 37.4
speed of ball when bat swing 9.2 m/s: 27.7
Difference 9.7 m/s

• 2-4. Which made the greater difference, doubling the bat weight or doubling the bat speed?

2-4. Doubling bat speed

☆ **2-5. Which is more important when hitting for distance, bat weight or bat speed?**

2-5. Bat speed

Will you get more distance by increasing bat weight? No, you won't, unless you're unusually strong. For most hitters, a heavier bat means a *slower* swing, with a net *loss* of distance.

The selection of the correct bat is important. Most players choose a bat that is too heavy. One expert suggests selecting a bat slightly *lighter* than the one that "feels just right" to you.

ACTIVITY EMPHASIS: The way a ball rebounds after being hit depends on its elasticity. This property of elasticity varies with several different factors.

MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter. See "Advance Preparations" in ATE front matter.

ACTIVITY 3: STRIKING THE BALL

Knowing what will happen to the ball when it is struck is important in games like golf, baseball, tennis, handball, and soccer. If you misjudge how hard the ball has been hit or kicked, or if you strike the ball the wrong distance, you can blow the play.

Figure 3-1 below shows a tennis ball hitting a tennis racket during a powerful serve.

3-1. It is being compressed.

• 3-1. What is happening to the tennis ball itself as it is struck?

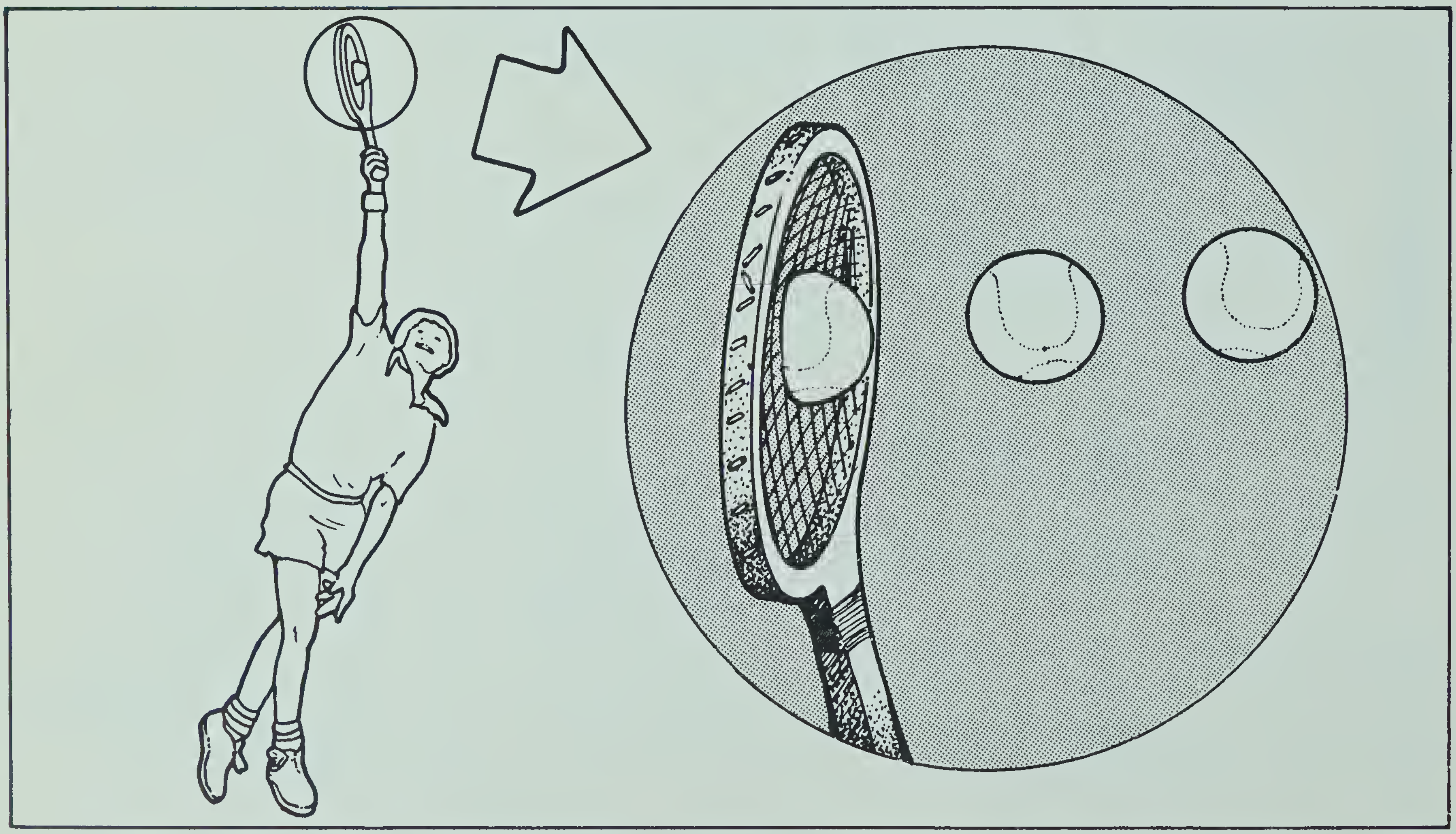
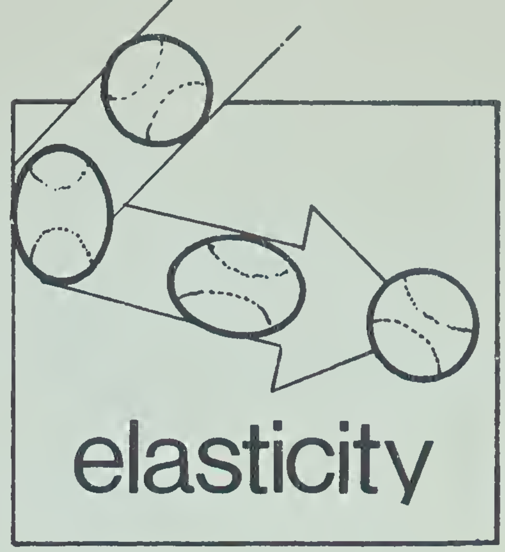


Figure 3-1

Most balls return to their original shape after they have been hit. This causes them to spring (rebound) from the surface of the striking object. The property of a ball that causes it to regain its original shape is called its *elasticity*. The greater a ball's elasticity, the faster it will return to its original shape and the farther it will rebound when it is hit or kicked. If a ball is soft and has poor elasticity, it will not come back to its original shape as quickly. Thus it will rebound poorly and not travel as far.



- 3-2. What causes a ball to rebound after being hit?

3-2. The ball returning to its original shape

☆ **3-3. What effect does a ball's elasticity have on how far it will travel when it is hit or kicked?**

3-3. The more elasticity a ball has, the better it will rebound and the farther it will go.

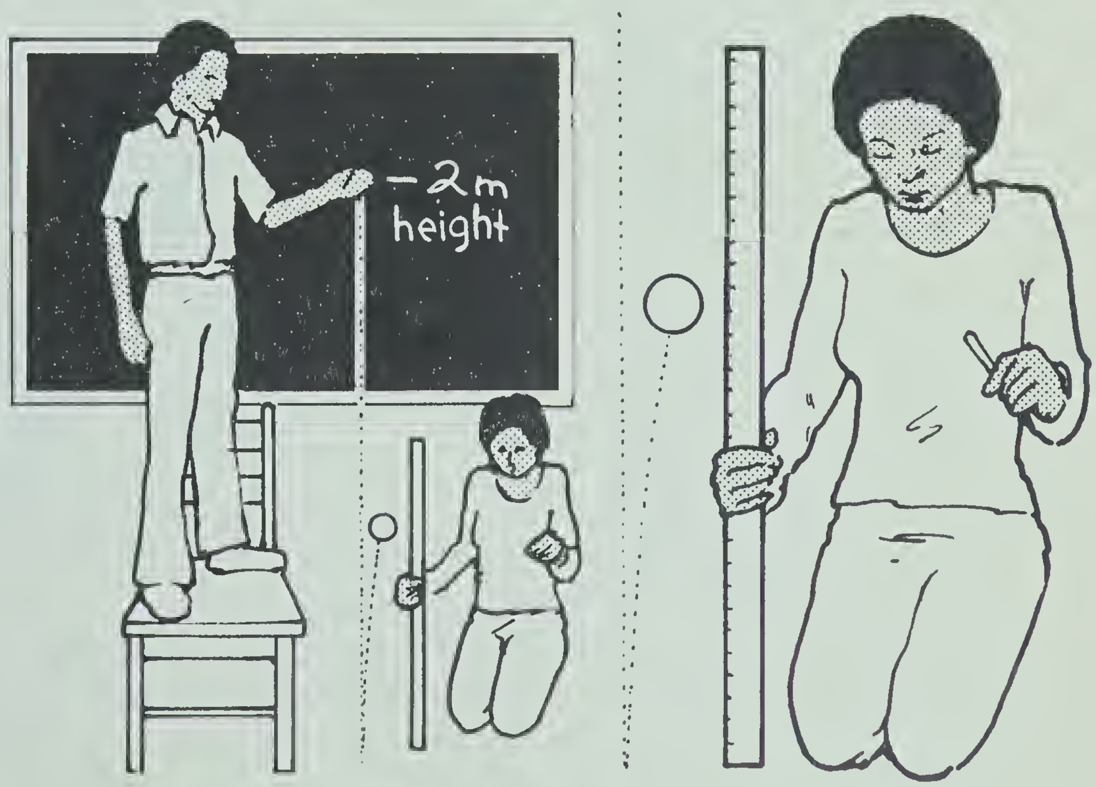
Of course, not all balls have the same elasticity. Some rebound more than others after impact. You can find out how the elasticity of balls differs by doing a simple investigation. You will need a partner (to help you with the measurements) and the following equipment.

5 different kinds of balls (golf, tennis, soccer, etc.)
piece of chalk, metre stick

A. In your notebook, make a table like the one shown. Enter the names of the kinds of balls in the spaces at the tops of the columns.

TRIAL	KIND OF BALL				
1					
2					
3					
Average					

B. On a wall or blackboard, make a mark about 2 m above the floor. Drop one of the balls from this height. Have a partner carefully estimate how high the ball rebounds from the floor, and record the rebound height in the notebook. Drop the ball for two more trials.



C. Repeat the three drops with each of the five balls. Enter the rebound heights in the table. Then find the average of the three trials for each kind of ball and enter those figures in the table.

Are you able to compute the averages? If not, look at "Resource Unit 1: Averaging" right now. Then finish Step C.

3-4. [Answers will vary, but highest ball is most elastic. Typical rebound heights: tennis ball, 100 cm; golf ball, 130 cm; table-tennis ball, 120 cm]

● 3-4. In your investigation, which ball rebounded highest? Why?

The surface onto which the ball is dropped can result in different rebound heights. For instance, a table-tennis ball that rebounded 120 cm on a tile floor rebounded only 10 cm on a carpeted hall and not at all on a shag carpet.

If you have a refrigerator or a warming oven in your science department, this might make a good extension activity. Use a ball whose elasticity doesn't depend on air pressure.

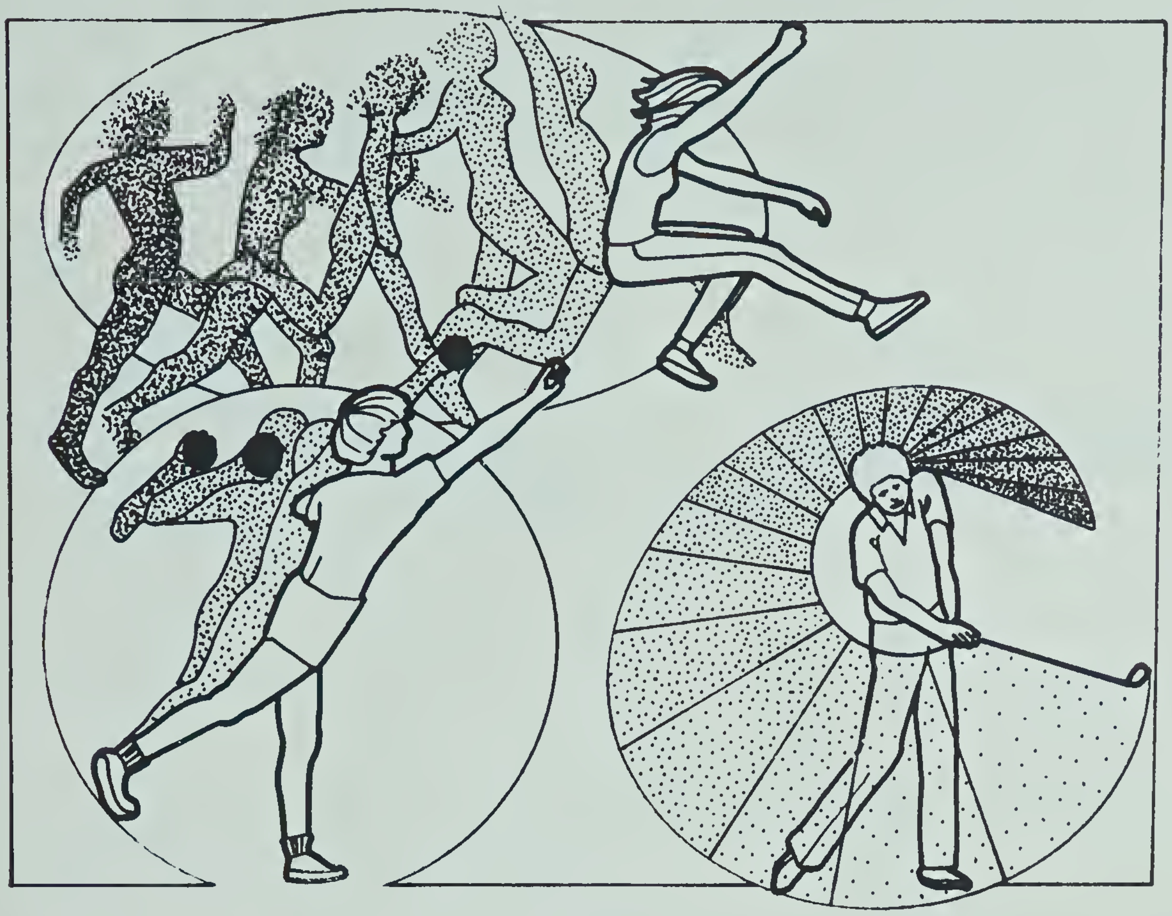
Your investigation showed that different balls rebound to different heights. This means they have different amounts of elasticity. What it didn't show is that a ball's elasticity is not always the same. It can change. Elasticity can be affected by such things as the amount of air in a ball, the newness of the ball, and the temperature of the ball.

3-5. It increases; it decreases.

● 3-5. What do you suppose happens to the rebound ability of balls that are heated? Of balls that are cooled? (You might like to design your own investigation to find out, if you have time.)

ACTIVITY 4: PROJECTILES

A track long jumper, a shotputter, and a golfer teeing off may not seem to have much in common. In some ways, however, they are alike. They must project an object into the air. And they must maximize the horizontal distance this object travels. The farther these athletes can jump, throw the shot, or hit the ball, the better their chances are of winning.



The distance an object travels in the air under ideal conditions depends on two factors. One is its *speed* (obviously the faster a ball is thrown, kicked, or hit, the farther it will go). The other is the object's *angle of projection*. Look at Figure 4-1 below. This shows the distance a shot will travel when projected at three different angles from ground level, but at the same speed.

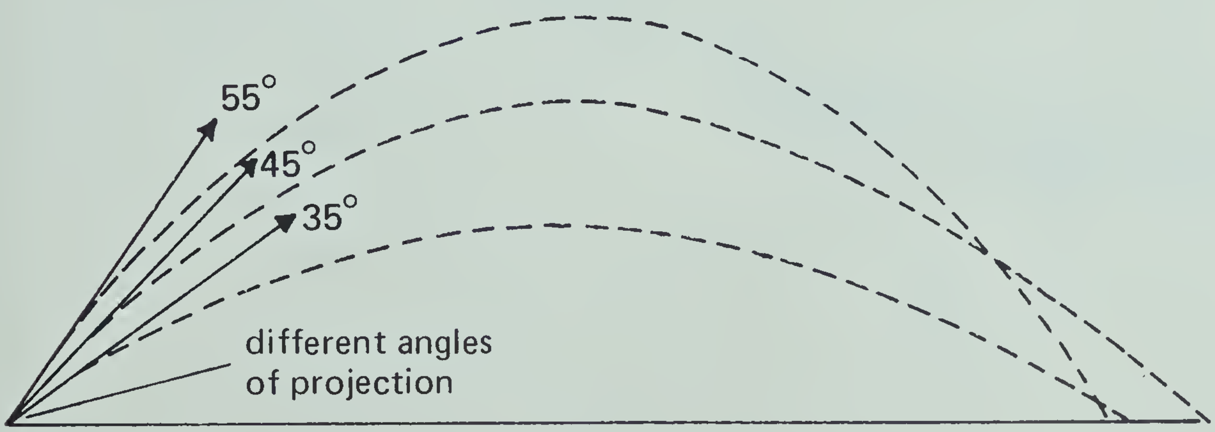


Figure 4-1

ACTIVITY EMPHASIS: The distance an object can be projected depends upon the speed and the angle of projection.

MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter. See "Advance Preparations" in ATE front matter.

Figure 4-1 shows the distance traveled for different angles without taking into account the fact that the shot is released about 2 m above the ground. The height above the ground when released affects the horizontal distance traveled. It also affects the best angle of projection.

4-1. Yes

● 4-1. According to Figure 4-1 on page 9, does the angle of projection affect the distance a shot will travel?

4-2. The speed of the object at release and the angle of projection

☆ **4-2. What two important factors affect the distance a hit, kicked, or thrown object will travel under ideal conditions?**

The follow-through in any sport is important to ensure that the force is applied to the object for the longest possible time.

As the distance over which the force is applied increases, the speed at which the object is projected increases. This knowledge has led to major changes in throwing techniques used in several sports. Shotputters, for example, now begin with their backs to their intended target area, instead of beginning sideways as they used to. The difference between the old and modern techniques is shown in Figure 4-2 below.

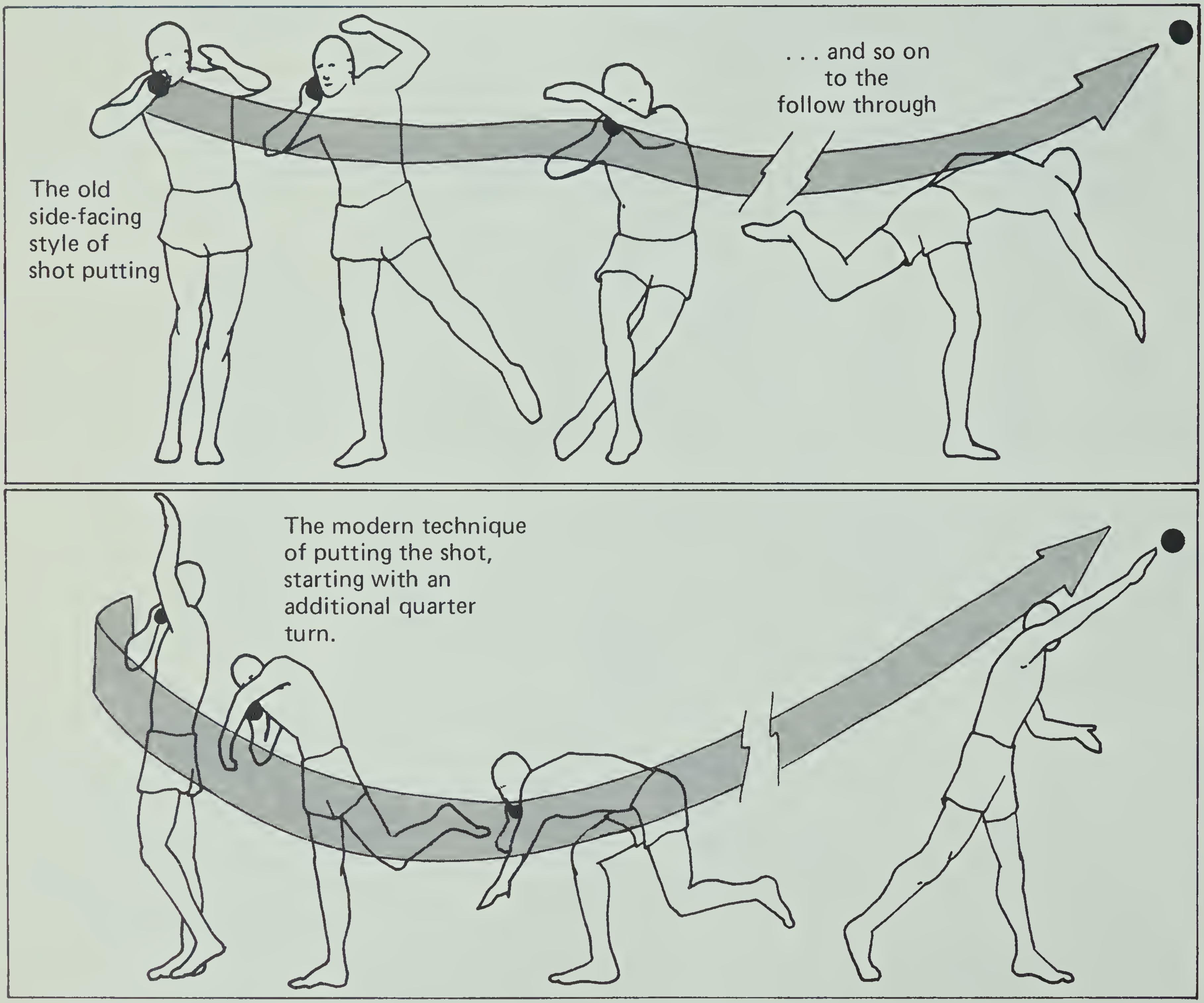


Figure 4-2

● 4-3. What advantage does the modern shotput technique have over the old one?

4-3. The force is applied over a longer distance (during an extra quarter turn).

☆ **4-4. If you increase the distance over which a constant force is applied to an object, what happens to the distance the object will travel?**

4-4. The distance of travel is increased.

The following experiment will help you understand how an object's speed and its angle of projection influence the distance an object will travel in air. For convenience and ease of measurement, you'll use water rather than a ball. You will need the following materials.

paper towels
bucket with tubing attachment
rubber tubing, 30 cm long
medicine dropper nozzle
cafeteria (or other shallow) tray
plastic ruler
spring clothespin
index card (8 cm X 10 cm)
protractor
transparent tape

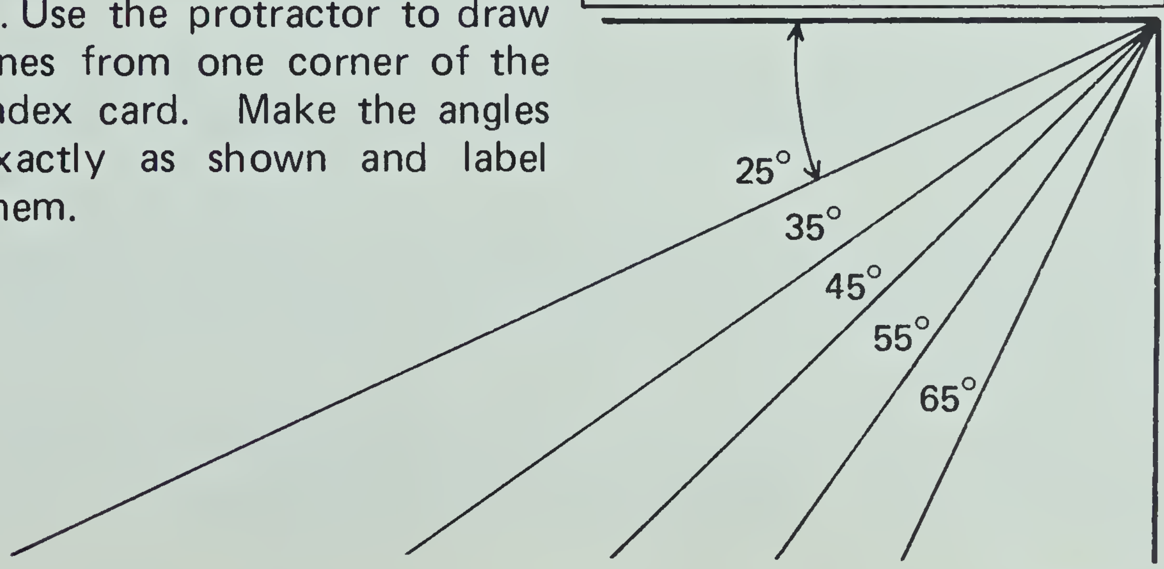
Do you know how to construct angles with a protractor? If you don't, look at "Resource Unit 8: Using a Protractor" before making this investigation.

Be sure to encourage student use of "Resource Unit 8: Using Protractors" if needed.

A. Now, copy this table in your notebook. You may want to make the spaces larger than the ones shown here.

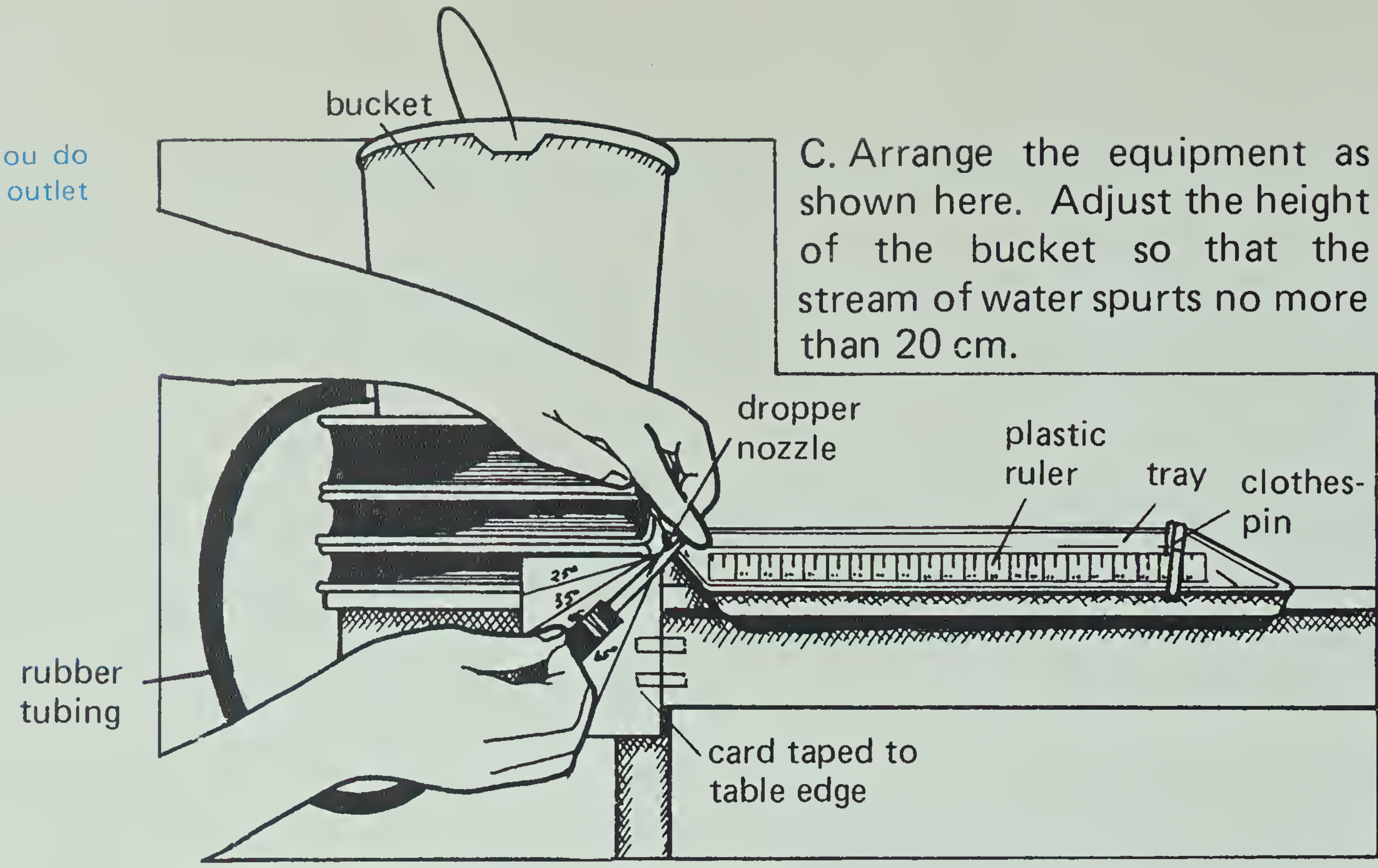
ANGLE OF PROJECTION	HORIZONTAL DISTANCE (in cm)
25°	
35°	
45°	
55°	
65°	

B. Use the protractor to draw lines from one corner of the index card. Make the angles exactly as shown and label them.

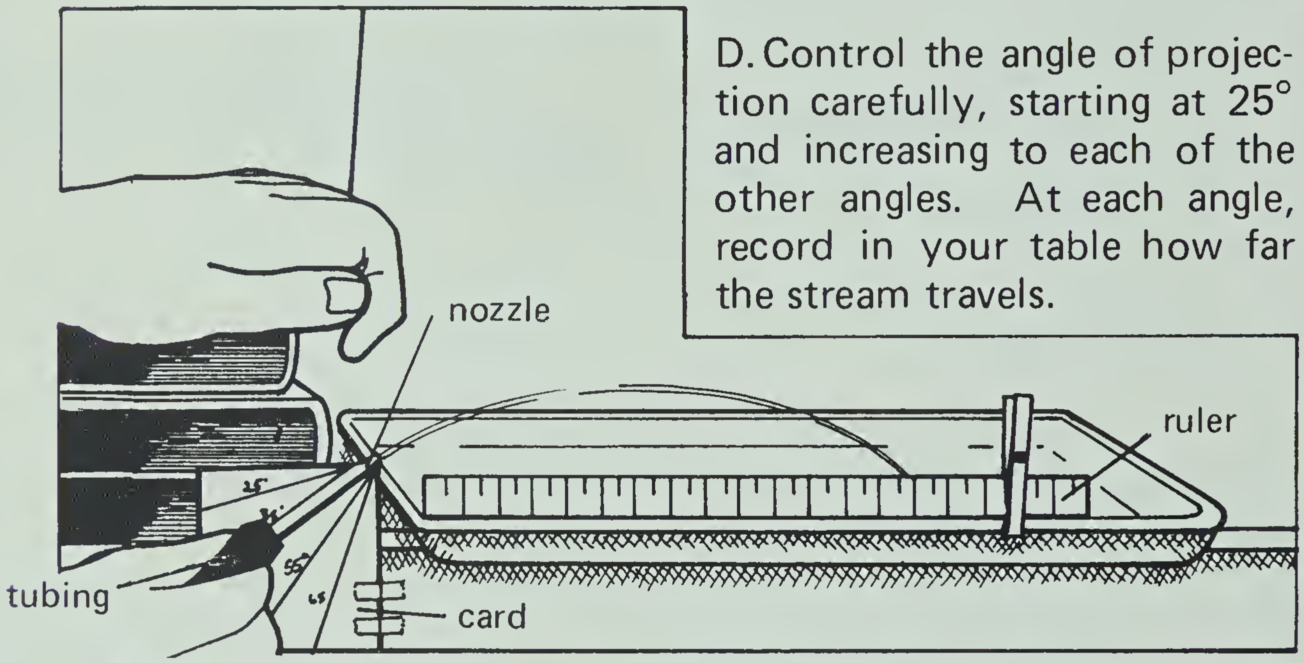


A siphon can be used if you do not have a bucket with an outlet at its base.

C. Arrange the equipment as shown here. Adjust the height of the bucket so that the stream of water spurts no more than 20 cm.



D. Control the angle of projection carefully, starting at 25° and increasing to each of the other angles. At each angle, record in your table how far the stream travels.



Speed of water is dependent on height difference between the water level and the nozzle opening.

For best results, keep the bucket refilled to the same level for each trial. This way the speed of the water will remain the same. Return the water from the tray to the bucket often.

4-5. Increased; increased; decreased; decreased

Sample data for a water level 10 cm above nozzle:

ANGLE	DISTANCE
25°	19 cm
35°	20 cm
45°	22 cm
55°	18 cm
65°	16 cm

- 4-5. Did the horizontal distance the water traveled increase or decrease as the angle was changed from 25° to 35°? From 35° to 45°? From 45° to 55°? From 55° to 65°?

4-6. 45°

- 4-6. For what angle did the water travel the greatest horizontal distance?

Into the wind, lower the angle; with the wind, increase it

Any projectile, be it water, a ball, or a bullet, will travel farthest for exactly the same angle — 45° (ignoring such factors as air resistance).

4-7. 45°

☆ **4-7. What is the angle of projection for maximum horizontal range of a football? Ignore any effects of air resistance.**

Increasing the *speed* that water comes out of the nozzle also affects how far the water stream will travel. You can easily change the speed by changing the height of the bucket. Perhaps you'd like to design your own activity to see this happen.

• 4-8. When you change the water speed, which is affected — the stream's height, its horizontal "carry," or both?

4-8. Both

Knowing the correct angle of projection won't make you a champion if you're just a beginner. But it will help you do your best. To improve even more, you will need to increase the projectile's speed at release. The way to do this will vary with the particular sport. Often it involves increasing the distance over which force is applied.

ACTIVITY 5: PUTTING SPIN ON THE BALL

ACTIVITY EMPHASIS: The spin on a ball will affect the path of its flight.

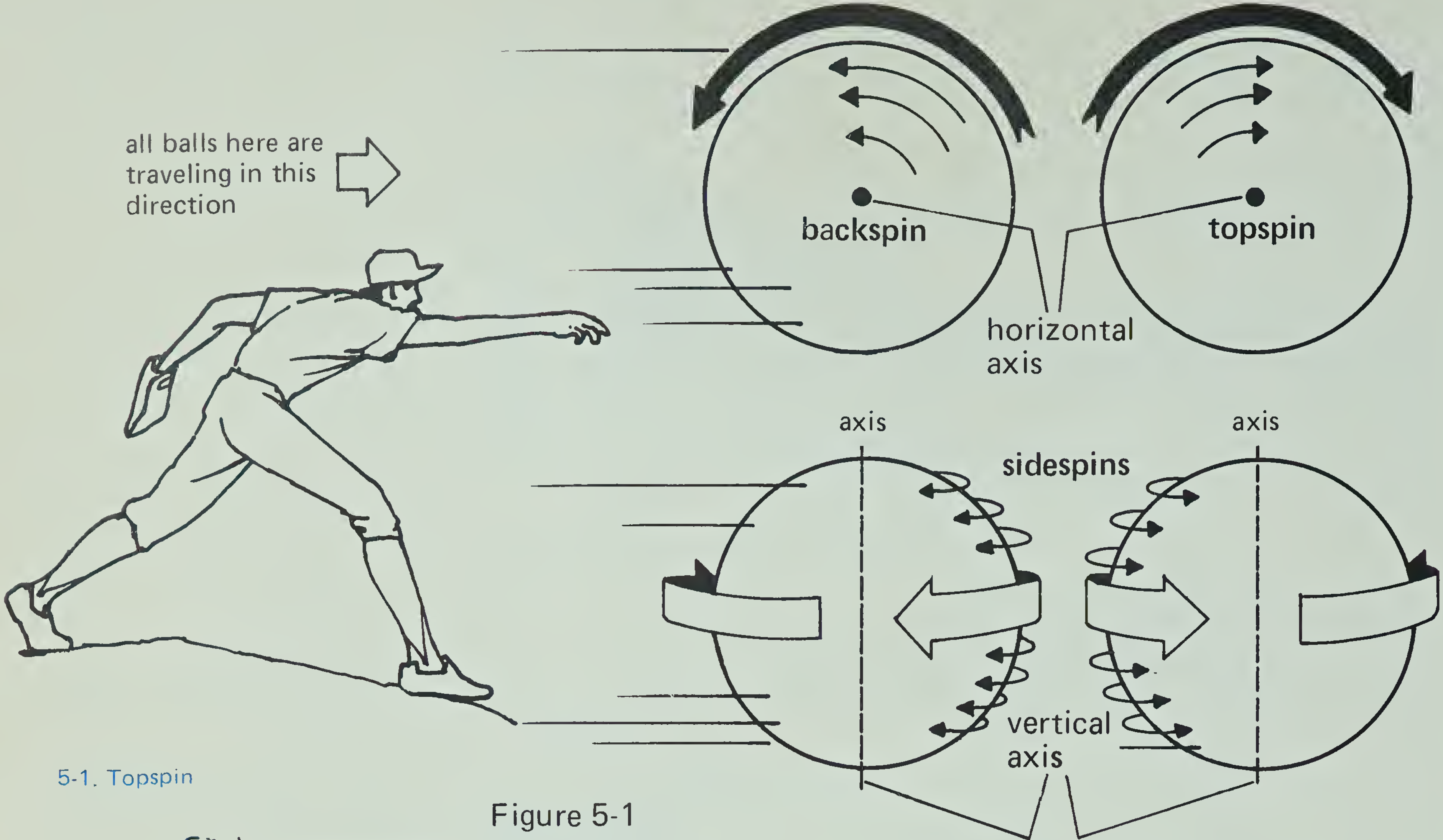
MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter.

Most balls spin (rotate) as they fly through the air. Both speed of rotation and direction of rotation affect what the ball does during its flight.

In sports like golf, tennis, baseball, and soccer, spin influences the path a ball will follow after it is hit, kicked, or thrown.

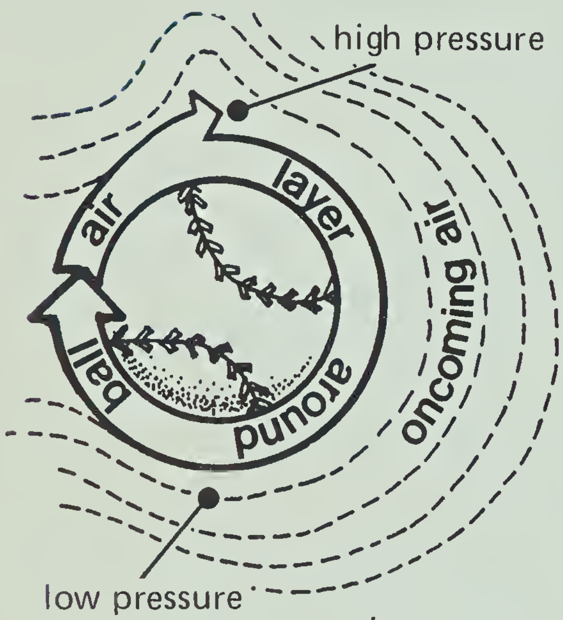
How do you make a ball rise? Drop? Curve right or left? The answers can help you better understand some sports, or improve your own game.

It is useful to describe spin in relation to some imaginary axis on the ball. Look at Figure 5-1 on page 14.



5-1. Topspin

Figure 5-1



• 5-1. Suppose you rolled a ball across the floor, away from yourself. Would the roll of the ball resemble backspin or topspin?

As a flying ball rotates, it tends to carry with it a thin layer of air close to its surface. The interaction of this surface air with oncoming air creates a pressure difference.

If a ball has topspin, the surface air on top of the ball meets oncoming air head-on. This causes high pressure above the ball. The surface air on the bottom of the ball moves in the same direction as the oncoming air to create an area of low pressure. This pressure difference (high above, low beneath) results in the ball's curving downward faster than could be expected from gravity alone. Look at Figure 5-2 below.

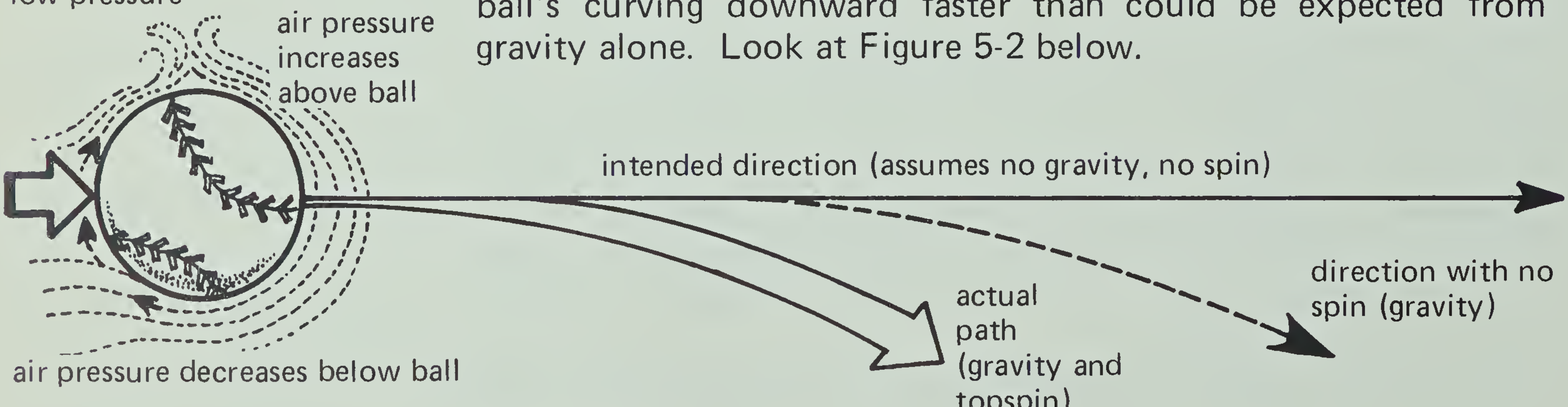


Figure 5-2

Now suppose the ball is thrown with backspin. The top of the ball is moving backwards, away from the direction of flight. A ball with backspin has reduced air pressure above the ball and increased air pressure below the ball. This difference in pressure overcomes some of gravity's pull. It keeps the ball from dropping as fast as a nonspinning ball would. The result is that although the ball still drops during its flight, it doesn't fall as rapidly as normally expected. This makes it *appear* to rise. (Figure 5-3 below.)

Backspin on a baseball can produce the "hopping" fastball if the pitch is thrown hard enough. In softball it's called a "riser."

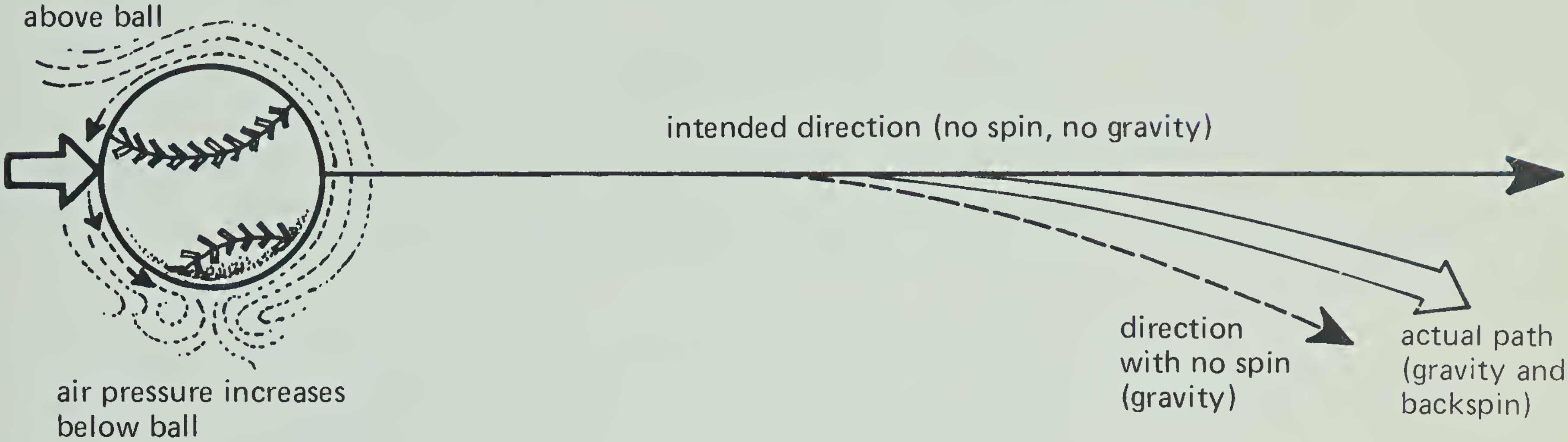


Figure 5-3

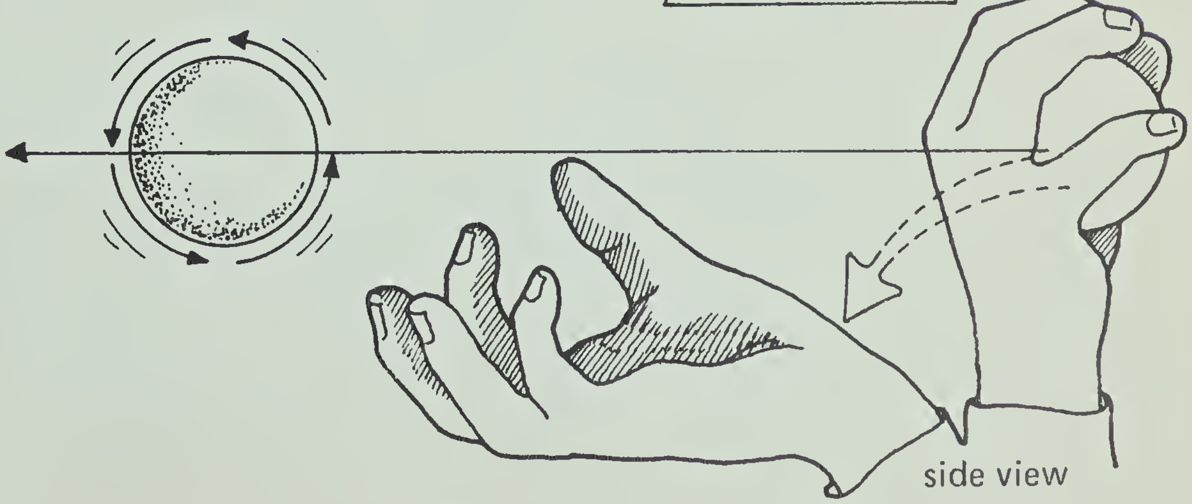
● 5-2. What kind of spin would you put on a ball if you wanted it to "drop"? If you wanted it to "rise"?

5-2. Topspin; backspin

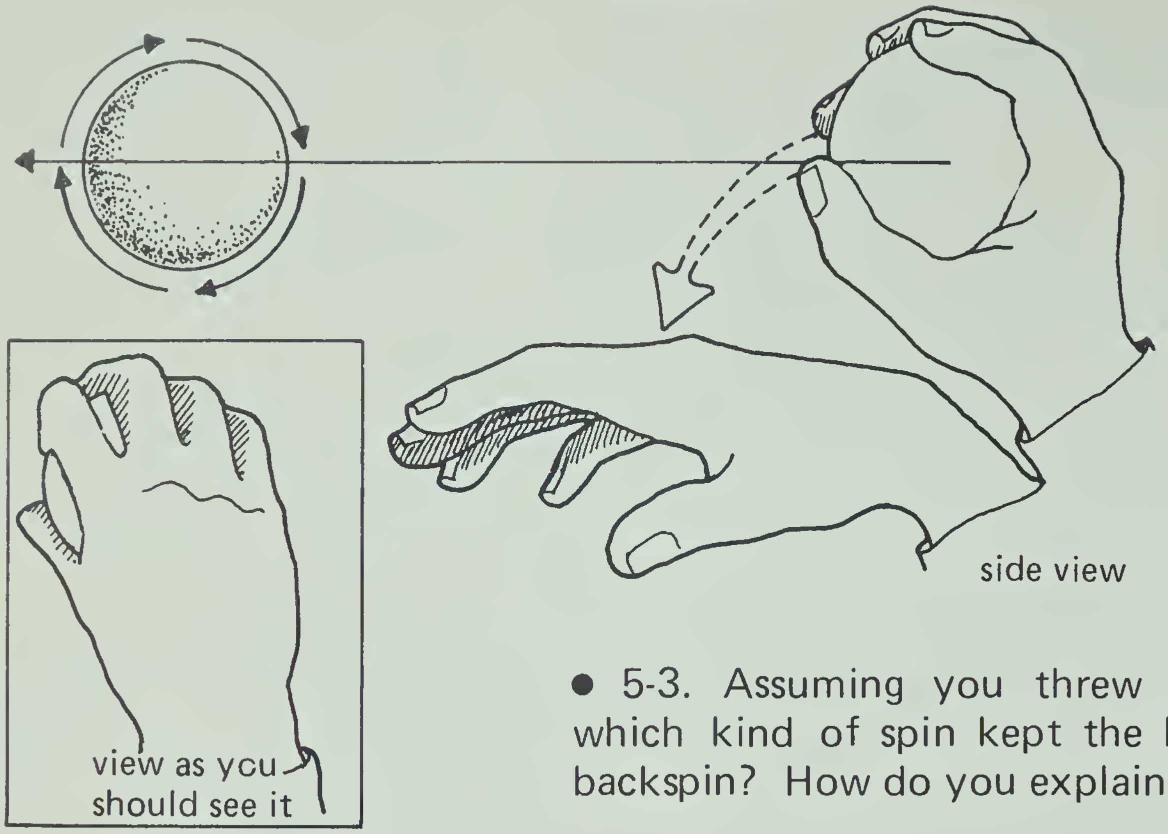
You can see for yourself how topspin and backspin affect a ball's flight. To do this you will need a partner to throw to, a windless spot (a corner of the gym, perhaps), and a Styrofoam ball about 8 cm in diameter (if none is available, use a table-tennis ball).

TOPSPIN

A. First practice throwing the ball with topspin. To do this, toss the ball backhanded to your partner as shown. Let your arm swing straight down, with the back of your hand towards your partner. The ball should roll off the ends of your fingers. Use only a lightweight Styrofoam or table-tennis ball.



BACKSPIN



B. Now try throwing with backspin. To do this, throw the ball straight overhand to your partner. Keep the back of your hand towards you. Let the ball roll off your fingertips as you release it.

● 5-3. Assuming you threw with the same force each time, which kind of spin kept the ball in the air longer, topspin or backspin? How do you explain this result?

5-3. Backspin; backspun ball partially overcame pull of gravity.

When a ball spins around its *vertical* axis, pressure builds up on one side of the ball or the other (depending on the direction of the ball's spin). This causes the ball to curve either right or left, producing sidespin. Look at Figure 5-4 below.

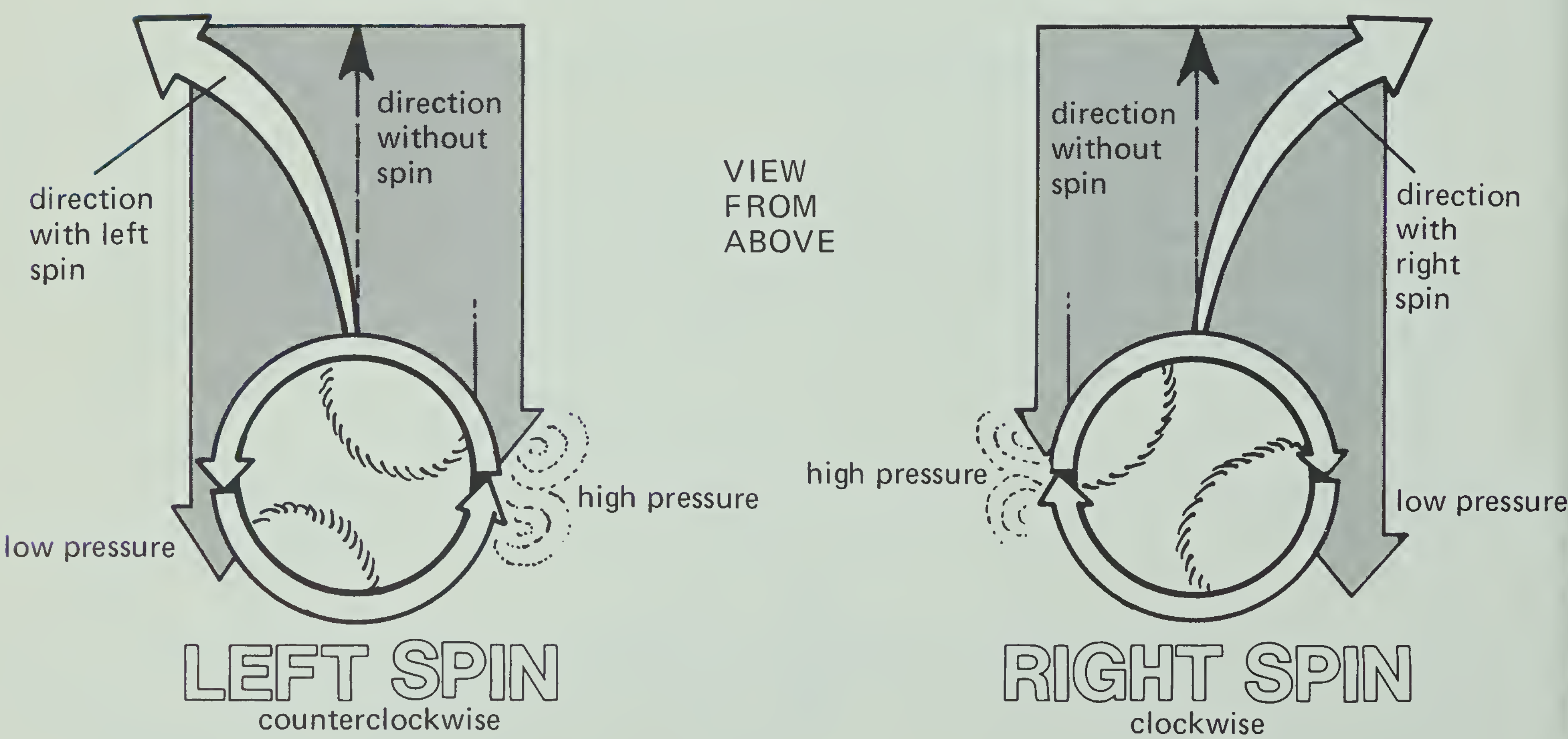


Figure 5-4

☆ 5-4. What causes a spinning ball to curve?

☆ 5-5. A ball with clockwise spin about its vertical axis (viewed from above) will curve in what direction as it flies through the air?

A good baseball pitcher frequently uses sidespin to throw curving balls that fool the batter. By putting rapid sidespin on a ball, a pitcher can cause a ball to curve or "break" up to 38 cm. Practice throwing a few breaking balls with right and left spin. Get a partner and see how well your spinning Styrofoam balls curve. Use only a lightweight ball.

Sidespin is not always helpful, however. In golf, both hooking (left spin) and slicing (right spin) are usually the result of poorly hit shots. Most amateurs *try* to hit the ball straight.

5-4. Air pressure on one side of the ball is greater than on the other side of the ball.

5-5. To the right

At one time, many people regarded the curve ball in baseball as an optical illusion. Dizzy Dean is reputed to have said: "Stand behind that tree down there and I'll hit you with an optical illusion."

A *screwball* in baseball breaks down and in on a likehanded batter. See if your students can figure out why screwball pitchers have short careers.

Right-handedness is here assumed.

ACTIVITY 6: THE WAY THE BALL BOUNCES

In most sports where a ball is used, you want the ball to go to a certain spot. And to get it there, you often have to bounce the ball off some surface. The surface may be a basketball backboard or the cushion (side) of a pool table. Or it may be the baseball bat or tennis racket you are holding as you play. In any case, you need to know just which way the ball will bounce.

ACTIVITY EMPHASIS: A nonspinning ball's angle of rebound from a plane surface (its angle of reflection) is equal to its incoming angle (angle of incidence).

MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter.

In pool, for example, you sometimes have to bank the cue ball off the cushion in order for it to hit another ball. To be successful in this, you must be able to predict the cue ball's path. And you can. Look at Figure 6-1 below.

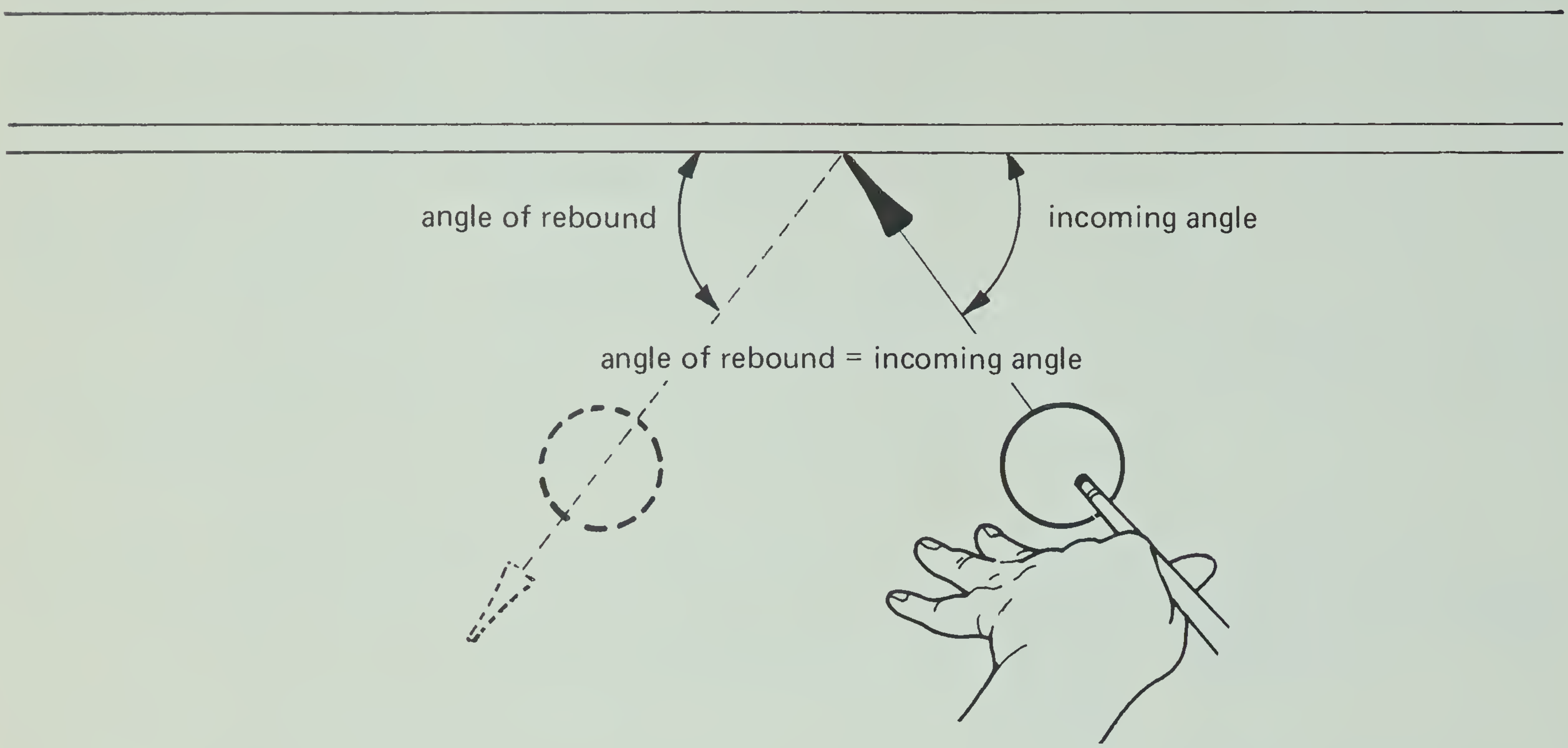


Figure 6-1

6-1. 52°

• 6-1. If the ball's incoming angle is 52°, what is its angle of rebound?

The simple rule illustrated in Figure 6-1 above can help you plan your pool shots correctly. In fact, it will work pretty well for any bouncing round object that is not spinning.

6-2. The angle between the struck surface and the rebounding ball

• 6-2. The *incoming angle* can be defined as the angle between the struck surface and the path of the incoming ball. How would you define the *angle of rebound*?

Specifically, a game of "eight-ball." The shooter wants to sink solid-color balls only.

Suppose you are playing a game of pool and are faced with the situation shown in Figure 6-2 on page 19. You want to hit the white cue ball so that it strikes one of the "solid" balls (either No. 1 or No. 7) and knocks it into the side pocket. To do this, you must bank the cue ball off the cushion.

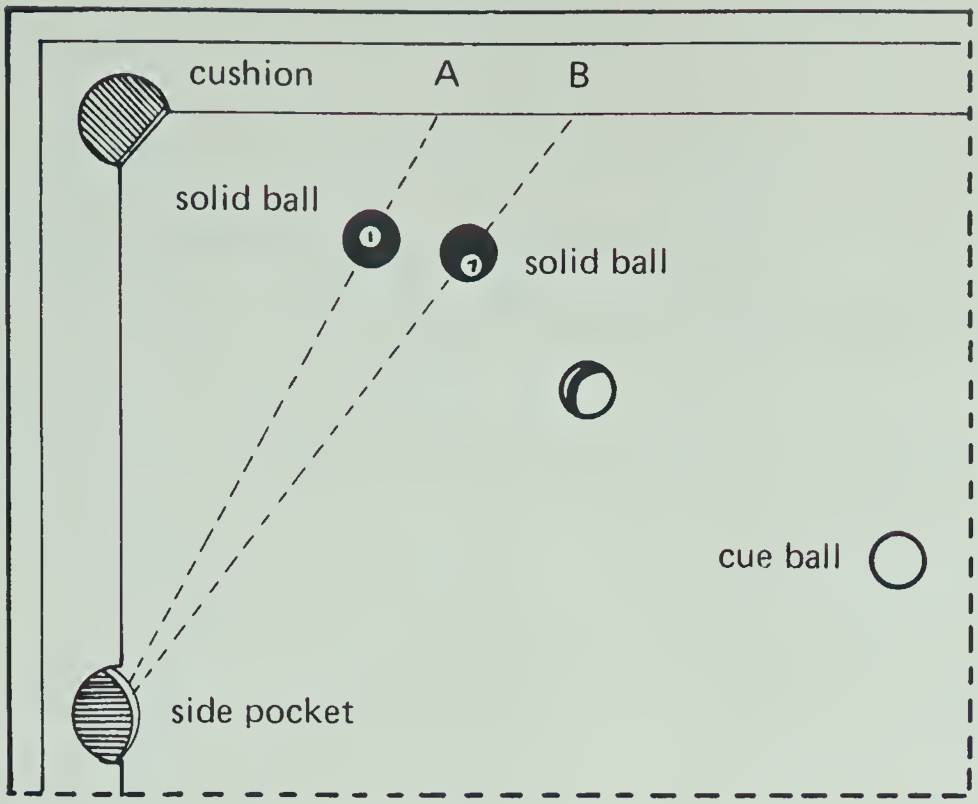


Figure 6-2

For such a shot as at No. 7, the cue ball must lie along the precise line. This setup will rarely occur unless the cue ball can be "spotted" (moved by the player to a desired and approved spot).

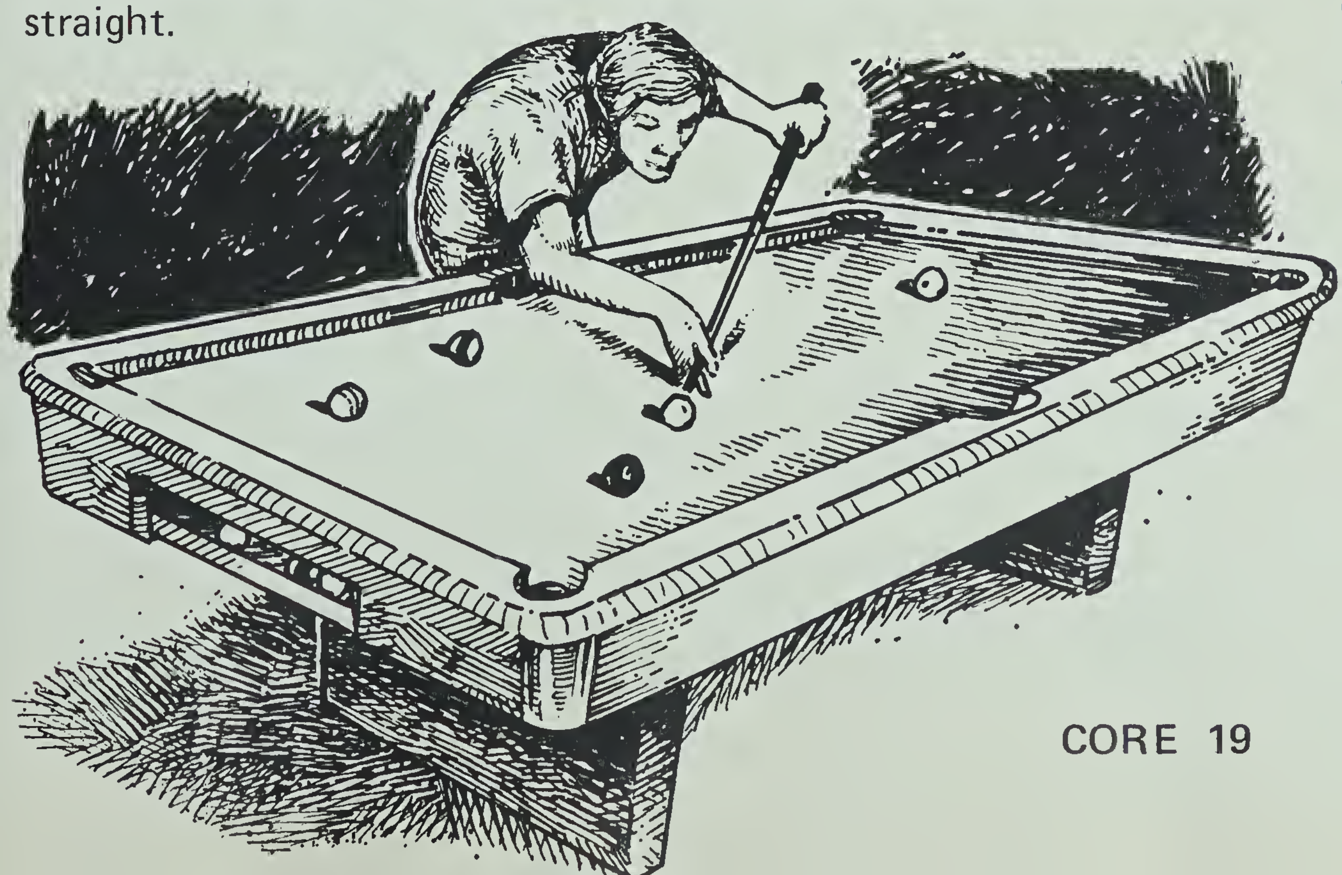
• 6-3. For a successful shot at the setup in Figure 6-2 above, which point on the cushion, A or B, should you aim at? Why?

To check your answer, measure the angles with a small protractor. (An easy way to form the incoming angles is to lay the edge of a pencil along the imaginary lines between the center of the cue ball and Aiming Points A and B. Pool players often use their cue sticks this way.) If you aren't sure how to measure angles with a protractor, look at "Resource Unit 8: Using a Protractor" before making your check.

Clearly, to succeed at pool you must be able to find the correct aiming point. Of course, you also have to shoot the ball straight.

6-3. B; the incoming angle to Point B (53°) will give an angle of rebound (53°) that sends the cue ball straight to Ball 7, which then goes into the side pocket. But the incoming angle to Point A (61°) will give an angle of rebound (61°) that makes the cue ball miss both Ball 1 and Ball 7 entirely.

Many of your students may be unfamiliar with the use of the protractor. You may need to insist on their using "Resource Unit 8: Using Protractors" or otherwise provide them with the instruction needed on measuring angles.



The angle of rebound is important in any game in which a ball is hit.

Understanding how a ball rebounds is also important when bunting or hitting a softball or baseball to a particular place on the field.

Figure 6-3 below diagrams a baseball infield. Suppose you wanted to bunt a ball down the third base line. How would you position your bat? Remember, the ball must be inside the baseline when it stops, or reaches third base, or is touched. Otherwise, the bunt will be ruled a foul.

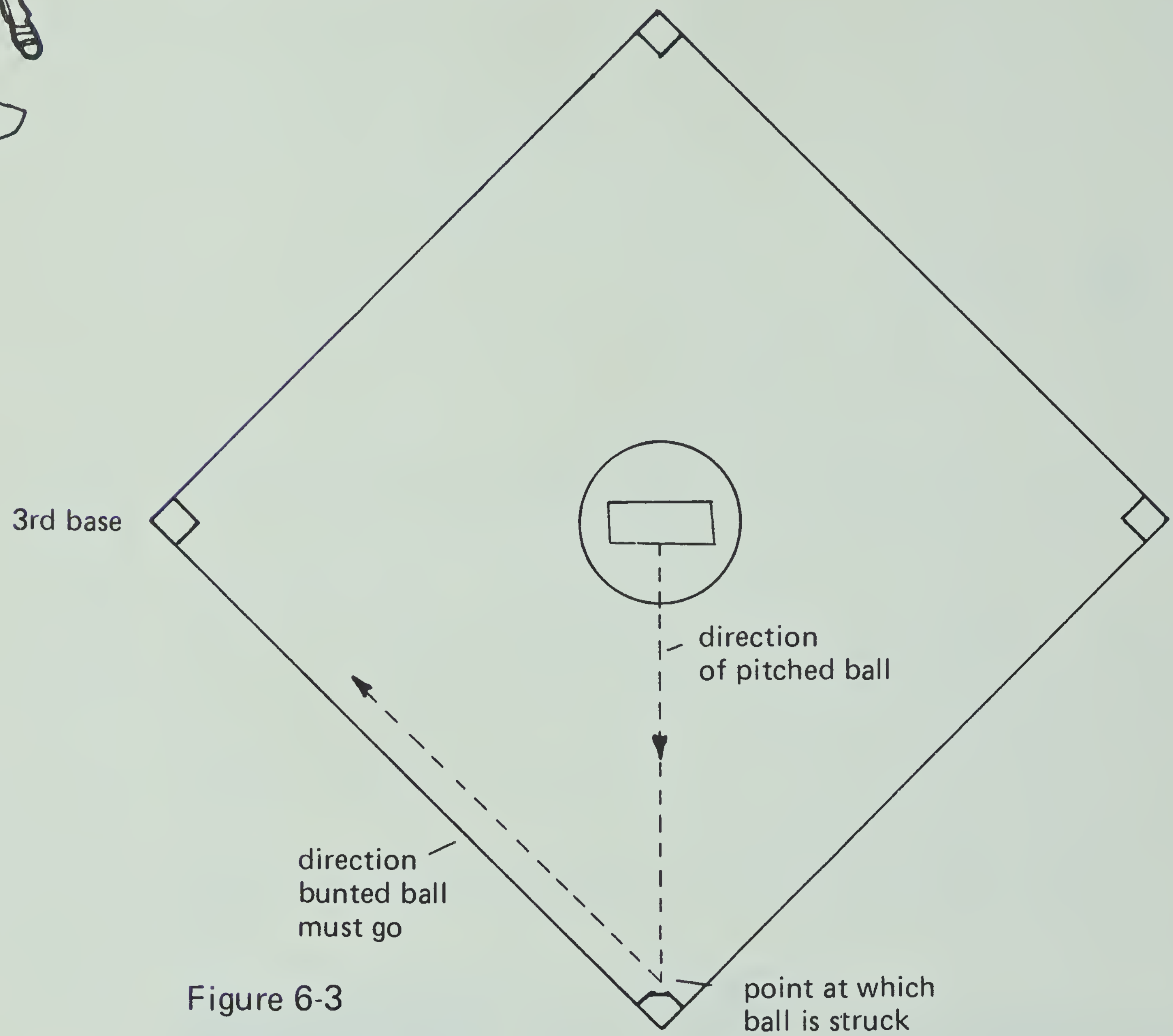


Figure 6-3

6-4. Back to the pitcher

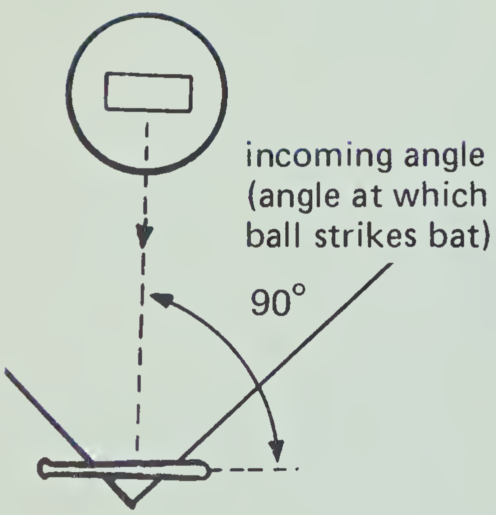


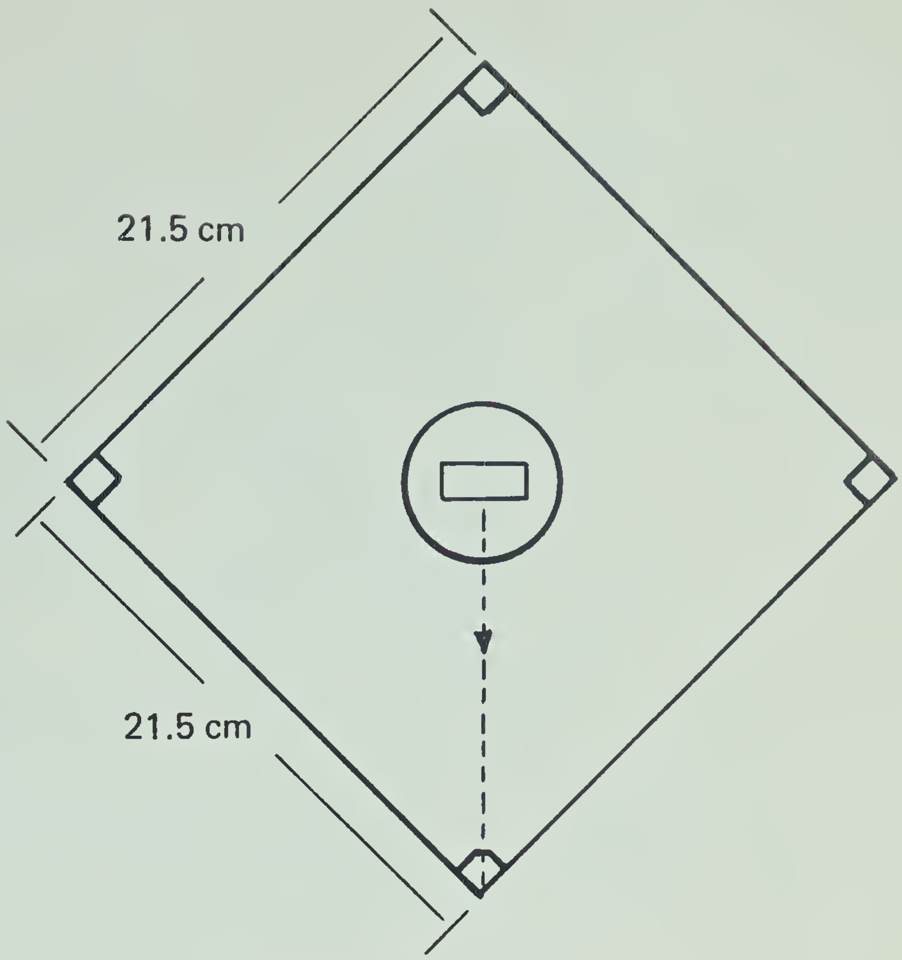
Figure 6-4

● 6-4. Look at Figure 6-4 on the left. If you hold your bat this way – perpendicular (⊥) to the direction of the pitch, where will the bunt go?

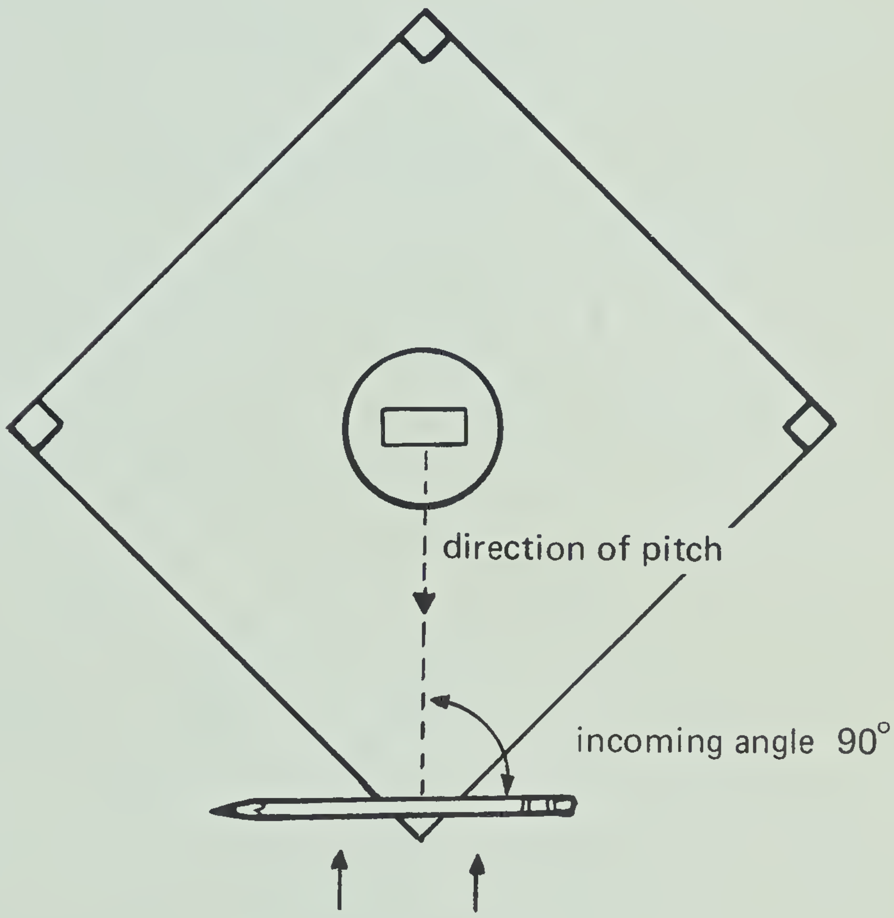
Try this for yourself. You can see how it works without going out to a ball field. You will need a partner, ten minutes, and the following materials.

round wooden pencil or 7 mm dowel
steel ball, 15mm in diameter
sheet of white paper, 21.5 cm square

A. The sheet of paper will be your ball diamond. Draw the bases and home plate in the corners as shown. Draw in the pitching mound and rubber in the center. Finally, connect the middle of the pitching rubber to the point of home plate with a dotted line (to mark the path of the "pitched" ball).



B. Hold the pencil (your "bat") in the fingers of both hands. Position it at home plate, perpendicular (⊥) to the pitch. Have your partner roll the "ball" to you from the pitching mound. Bunt the ball by pushing the bat straight toward the ball. Note which way the ball rebounds.

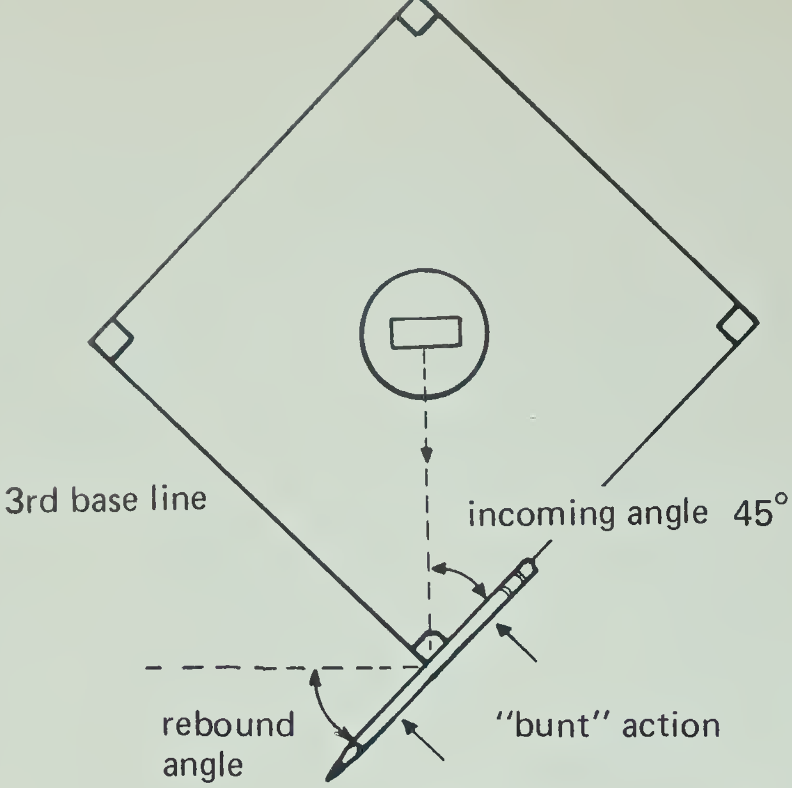


- 6-5. Which way did the ball rebound?

6-5. Back to the pitching mound (perpendicular)

- 6-6. What was the angle of rebound? (Remember your definition in Question 6-2 on page 18. Use the protractor to check the angle, if you wish.)

6-6. 90°



C. Now line up your bat perpendicular to the third base line. Have your partner roll the ball home again. Bunt the ball by pushing the bat toward third base. Note which way the ball goes.

6-7. To the left, outside the diamond; 45°

● 6-7. Where did the ball go? What was the angle of rebound?

Neither of your two bunts was very good. The first would probably be an easy out by the pitcher, and the second would be a foul ball.

To bunt the ball fairly down the third base line, you have to hold the bat in a direction about halfway between the two positions in Steps B and C.

6-8. 90°; 45°

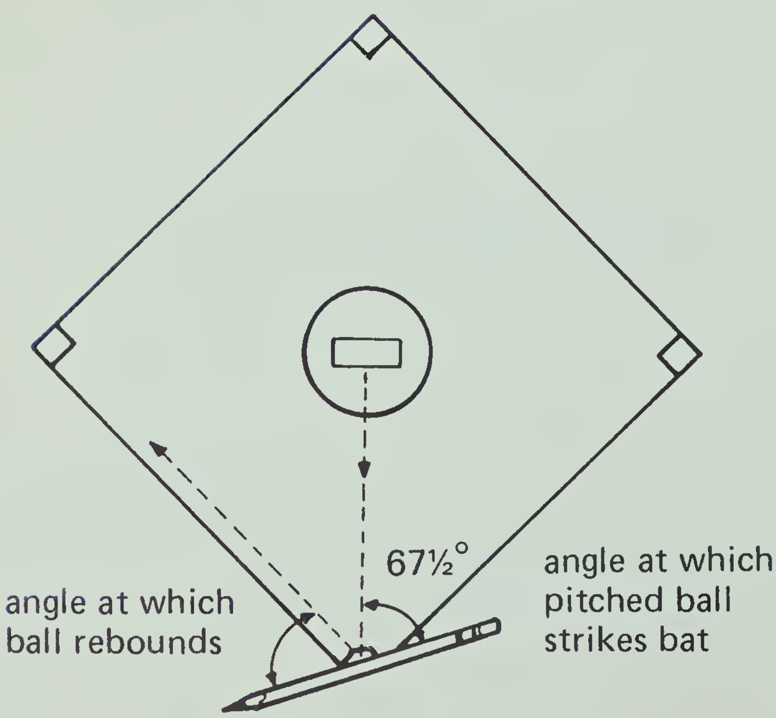
● 6-8. What was the incoming angle (and the angle of rebound) in Step B? In Step C?

6-9. 67½°

● 6-9. What angle is halfway between the incoming angles in Steps B and C? (Halfway between 90° and 45°?)

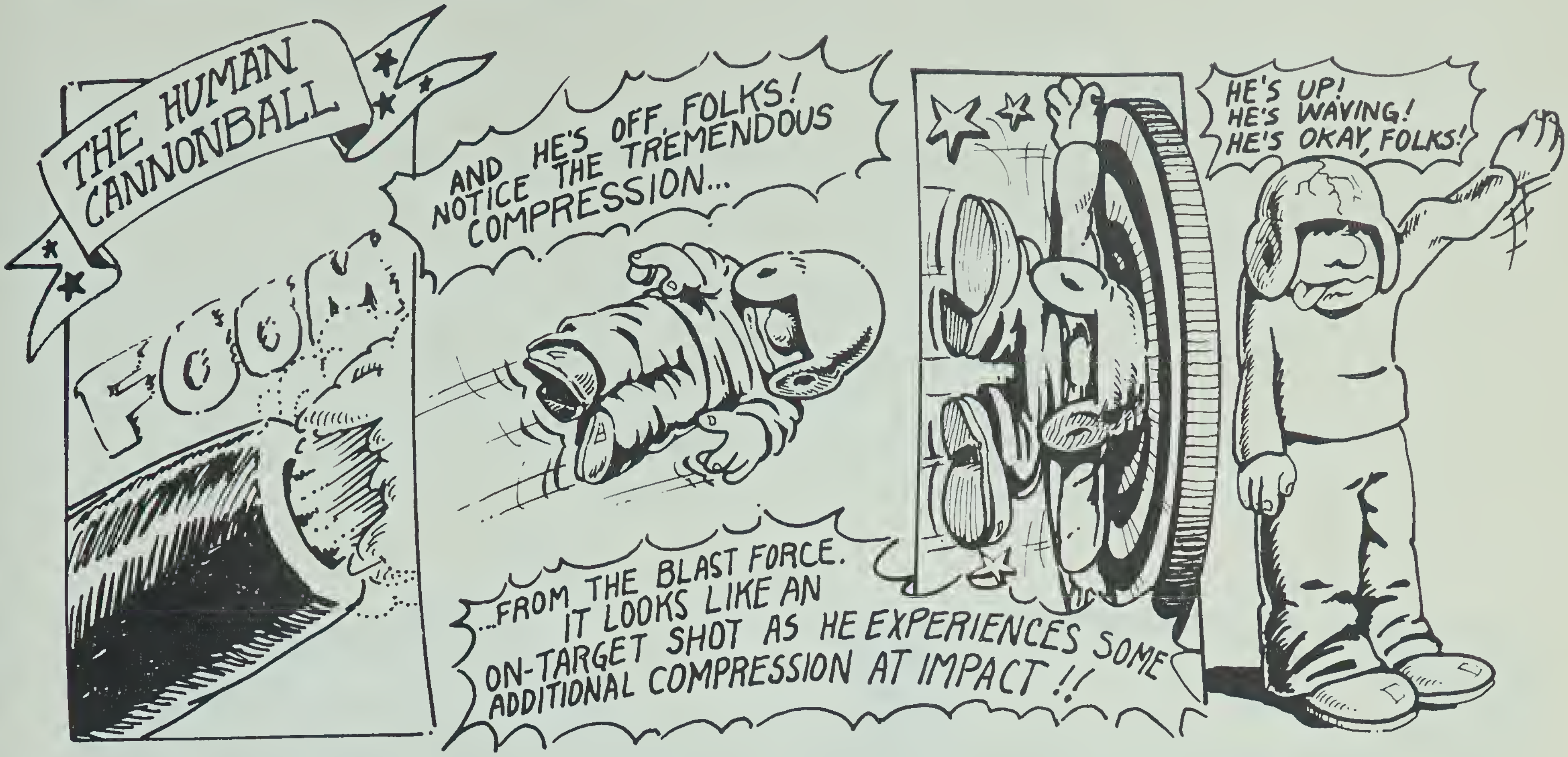
6-10. 67½°

☆ **6-10. If a pitched ball makes an angle of 67½° with the bat, what will be its angle of rebound?**



D. Check your answer by the procedure you used before. With your partner rolling the ball, try bunting from a bat angle that is *between* the ones you used in B and in C.

ACTIVITY 7: APPLYING FORCE



Moving fast is important in many sports. About 300 years ago, an English scientist, Sir Isaac Newton, formulated a law that, among other things, helps us understand how runners and swimmers achieve their best speed. This law has to do with *forces*. As you know, a force is a push or pull. Forces always produce a change in either the shape or the motion of any object that experiences them. (That's what the cartoon above is showing in a humorous way.)

ACTIVITY EMPHASIS: The direction that a force is applied is important in sports.

MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter.

Newton stated that for every action (force), there is an equal and opposite reaction (force). Look at Figure 7-1 below.

This is Newton's 3rd Law of Motion.

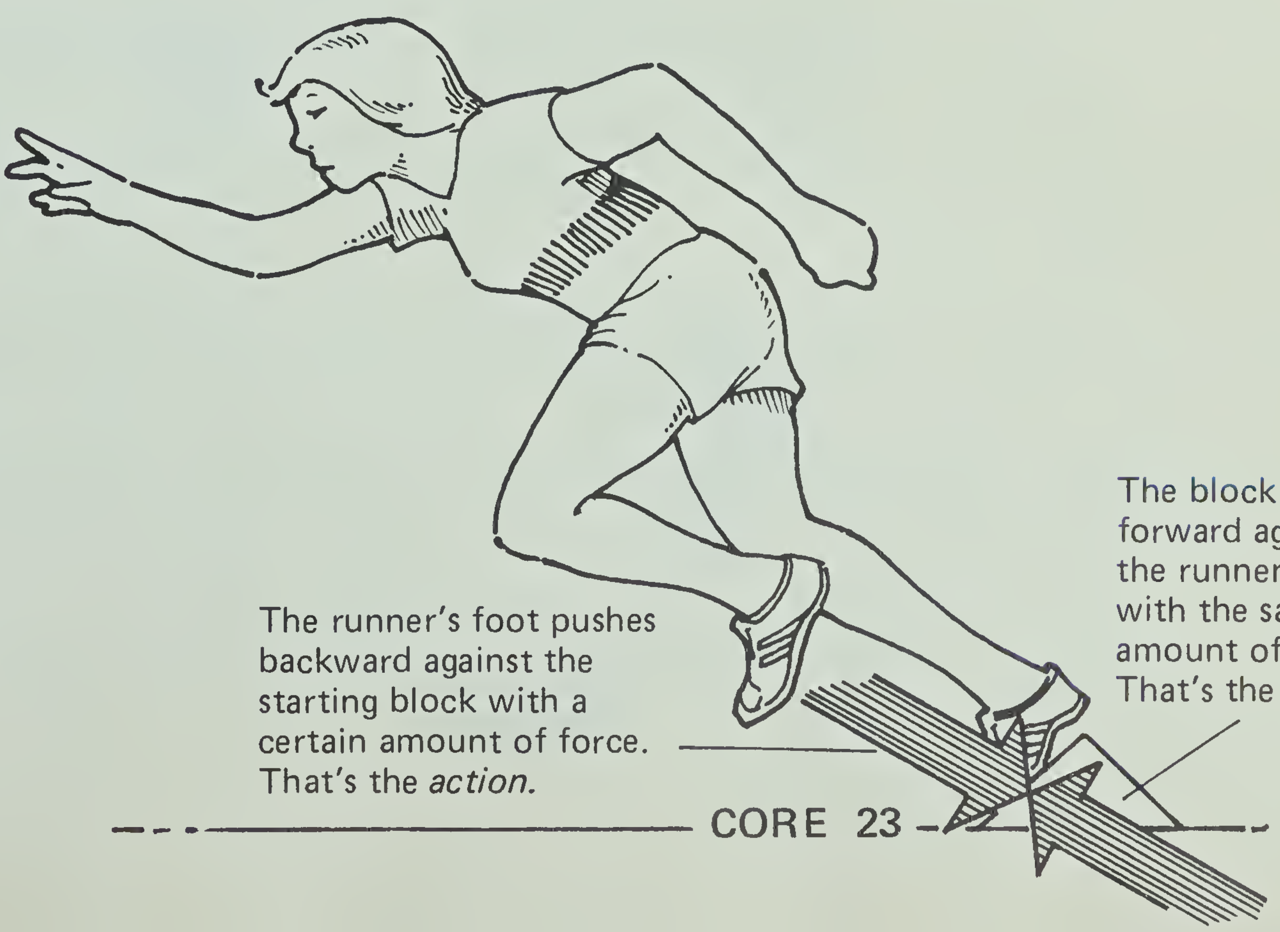


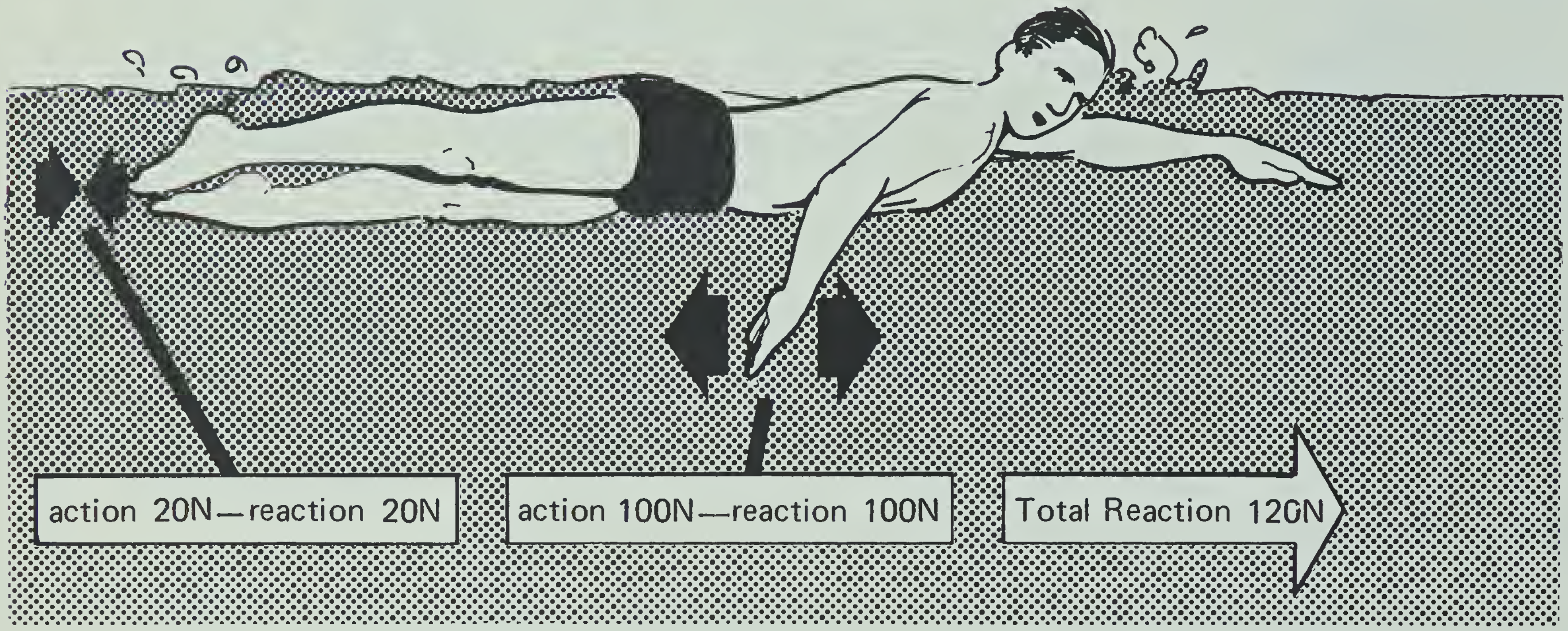
Figure 7-1

Force is measured in metric units called *newtons* (in honor of Sir Isaac). A newton is the amount of force required to raise a mass of 1 kilogram a distance of 1 metre per second.

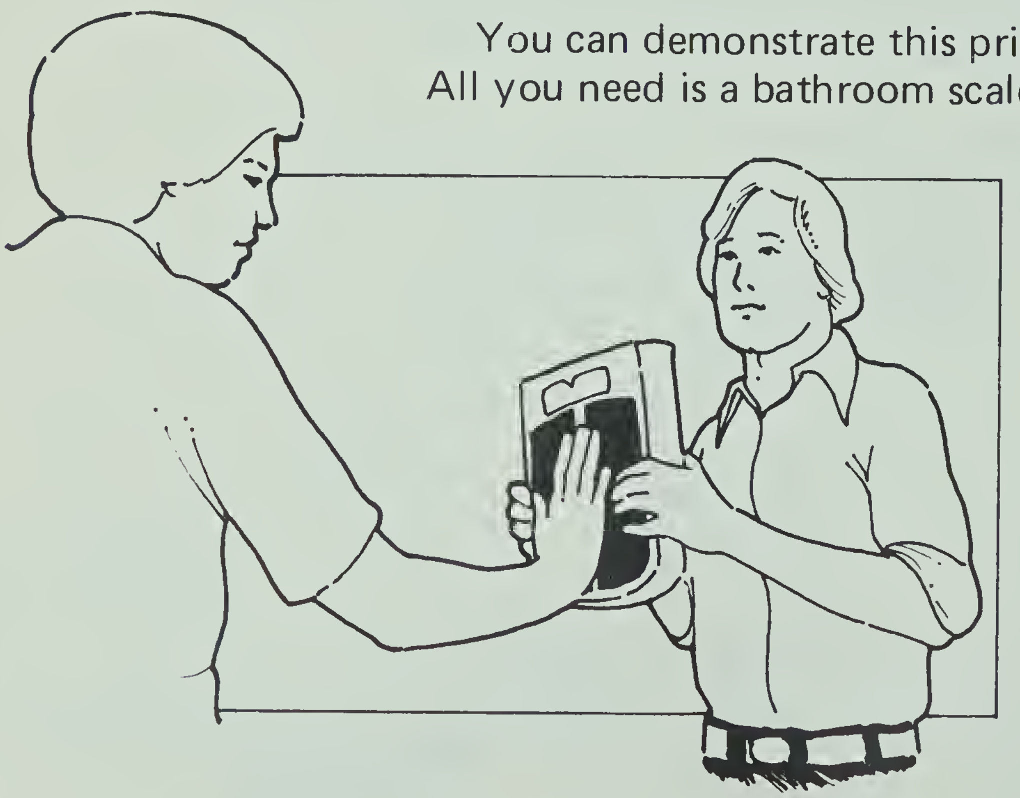
7-1. 650 N

● 7-1. If the runner pushes against the starting block with a force of 650 newtons, what is the force (reaction) pushing against his foot?

The same idea applies to swimming. If a swimmer pushes backward on the water with a force of 100 newtons (action) with an arm and 20 newtons (action) with the feet, a force (reaction) of 120 newtons is exerted on the swimmer by the water. This pushes the swimmer forward.



You can demonstrate this principle with a simple investigation. All you need is a bathroom scale and a partner.



A. Have your partner hold the scale vertically, with the dial and platform facing you. Tell your partner that the scale should be held motionless as you push against it. Then push gently against the platform, reading the dial as your partner holds the scale motionless.

• 7-2. With how much force did you push against the scale?

7-2. [Answers will vary.]

• 7-3. In order for the scale to remain motionless, how hard must your partner have pushed back in holding the scale?

7-3. The same amount as you pushed against the scale

Your push against the platform represents the *action*. Your partner's push to hold the scale motionless represents the *reaction*. The pushes must have been equal, or else the scale would have moved toward your partner or toward you. And the pushes were in opposite directions.

Perhaps it's not clear yet how this law of action and reaction affects running or swimming speed. Suppose you are trying to swim as fast as possible. To do this you must create as much force as you can with your arms and legs. And the force must be in the right direction.

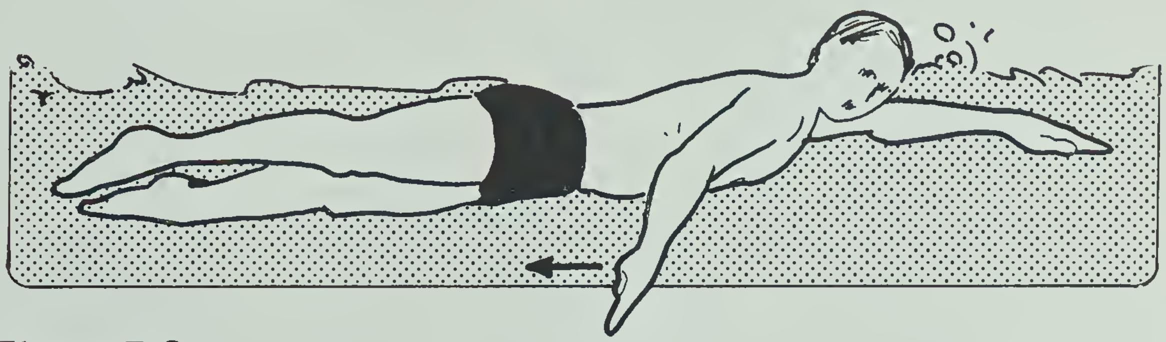


Figure 7-2

The swimmer in Figure 7-2 above is applying force in a backward direction as indicated by the arrow.

• 7-4. In what direction will the force of reaction push the swimmer in Figure 7-2 above?

7-4. Forward

Figure 7-3

• 7-5. When the swimmer in Figure 7-3 above applies force (action) with his left arm, what will happen to his body?

7-5. It will rise up in the water.

• 7-6. When the swimmer applies force with his right arm, what will happen to his body?

7-6. It will sink lower in the water.

The up-and-down bobbing created by this swimmer's arm action will cause him to swim much slower, with a lot of wasted effort.

7-7. Backward, opposite to your intended direction

☆ **7-7. In order to make best use of the force you apply in swimming, what direction should your arms push on the water during the stroke?**

Running fast, just like swimming rapidly, requires that you move forward by pushing backward. And, as in swimming, if you apply too much force downward when you run, you will bounce up and down. This will slow you, since much of your leg force is being used to lift your body, not to push it forward.

7-8. B; because B's foot is pushing backward more

☆ **7-8. In Figure 7-4 below, which of the two running positions, A or B, will produce the faster start? Why?**

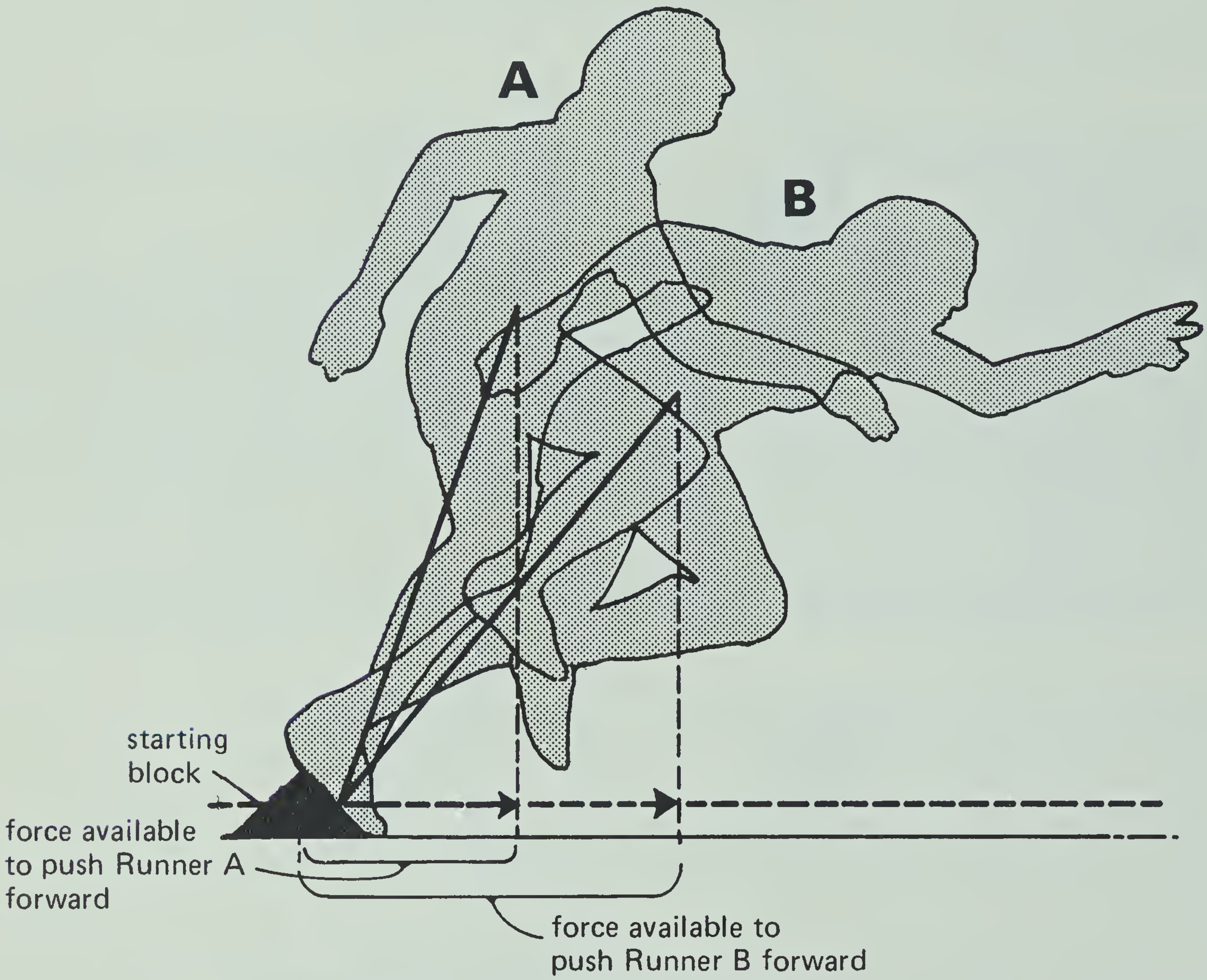


Figure 7-4

7-9. They allow the runner to push backward better, giving more forward thrust.

● 7-9. Why do many runners use starting blocks for short sprint races?

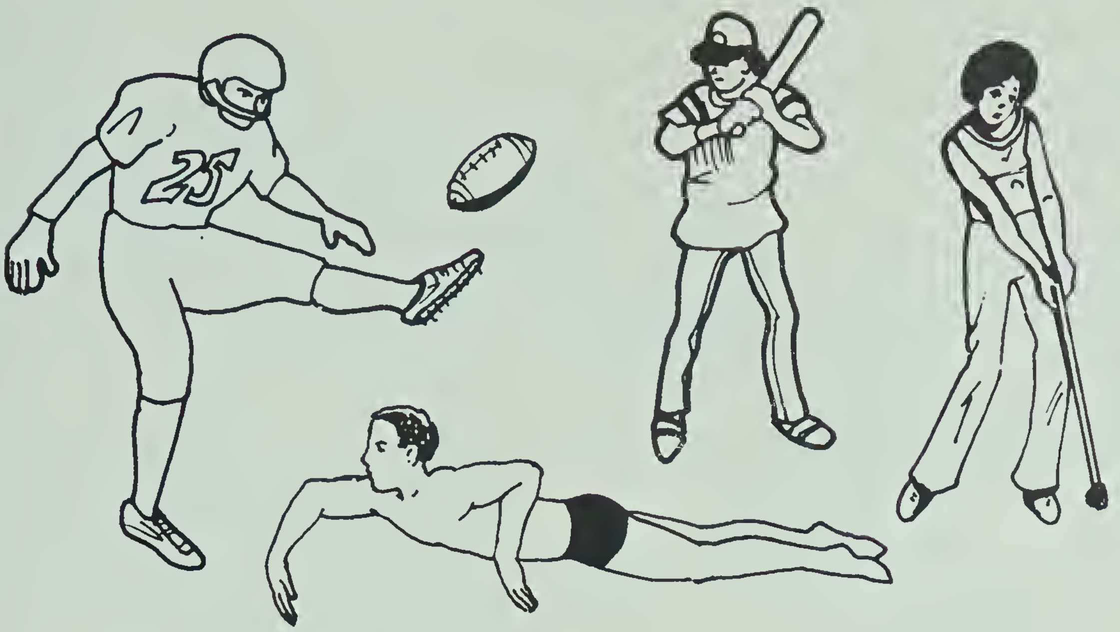
By making sure you direct your force in the proper way, you may not become a champion, but you will be able to run and swim faster.

ACTIVITY 8: EXTRA HELP

ACTIVITY EMPHASIS: Parts of the body act as natural levers either to increase force or to increase the relative range or speed of the resistance point.

MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter.

You may be aware that almost every day you use *levers*. You are using a lever when you stir a cup of coffee, open a can or bottle with a can opener, flip an egg with a spatula, turn a door handle, or shift gears in a car.



What you may not have realized is that your body itself contains quite a collection of levers. Your arms and legs, your fingers and toes, even your lower jaw, are natural levers. Knowing how to use your body levers efficiently can improve your sports performance. All the pictures above show body levers in action.

What is a lever, anyway? It is any essentially rigid object that transmits or modifies force by the use of three points. All levers, whatever their design, have these three points. Look at Figure 8-1 below.

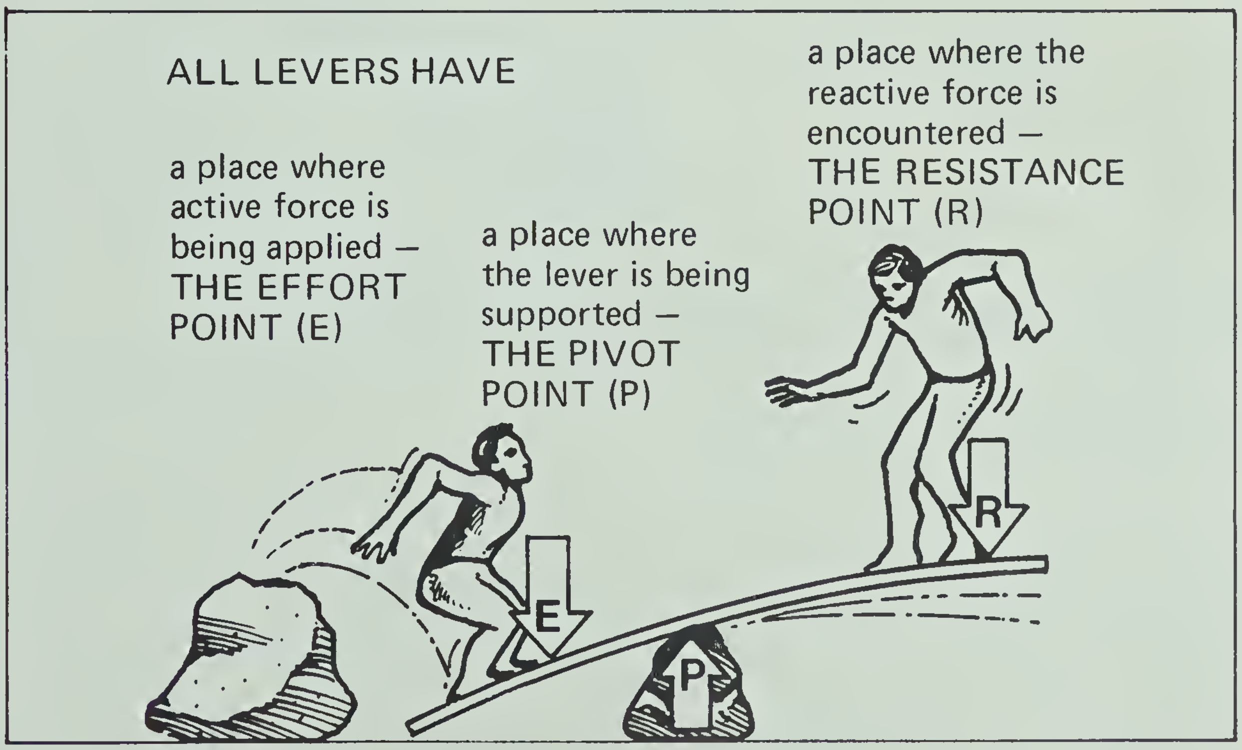


Figure 8-1

8-1. Effort point, pivot point, and resistance point

You may remember that traditionally there are 3 classes of levers. Class 1, with the pivot (fulcrum) between the effort and the resistance, is the same as Type 1 here. Classes 2 and 3 are here combined as Type 2.

• 8-1. What are the three points that all levers have?

Although all levers have the same three points, the *placement* of these points is not always the same. There are basically two types of levers (see Figure 8-2 below).

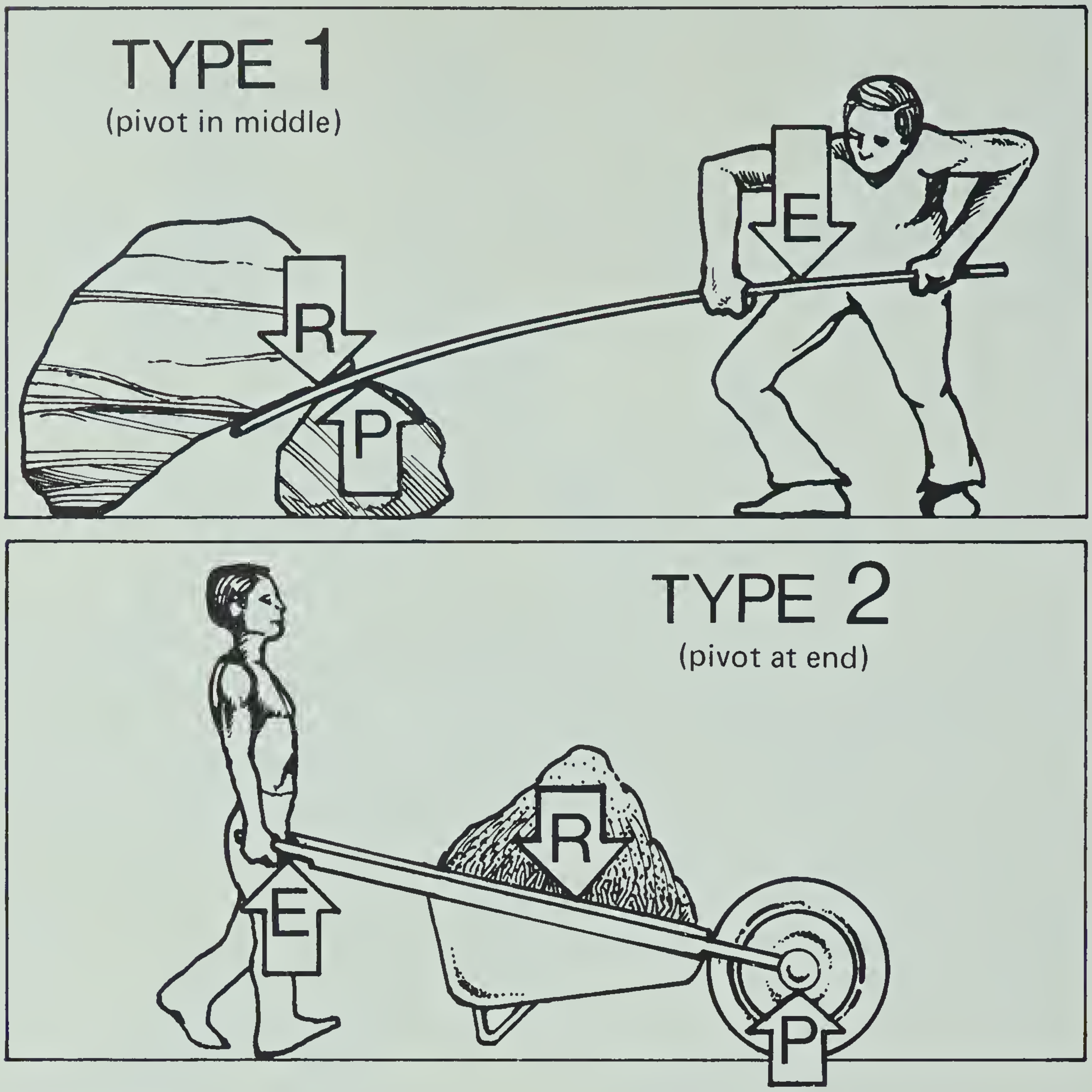


Figure 8-2

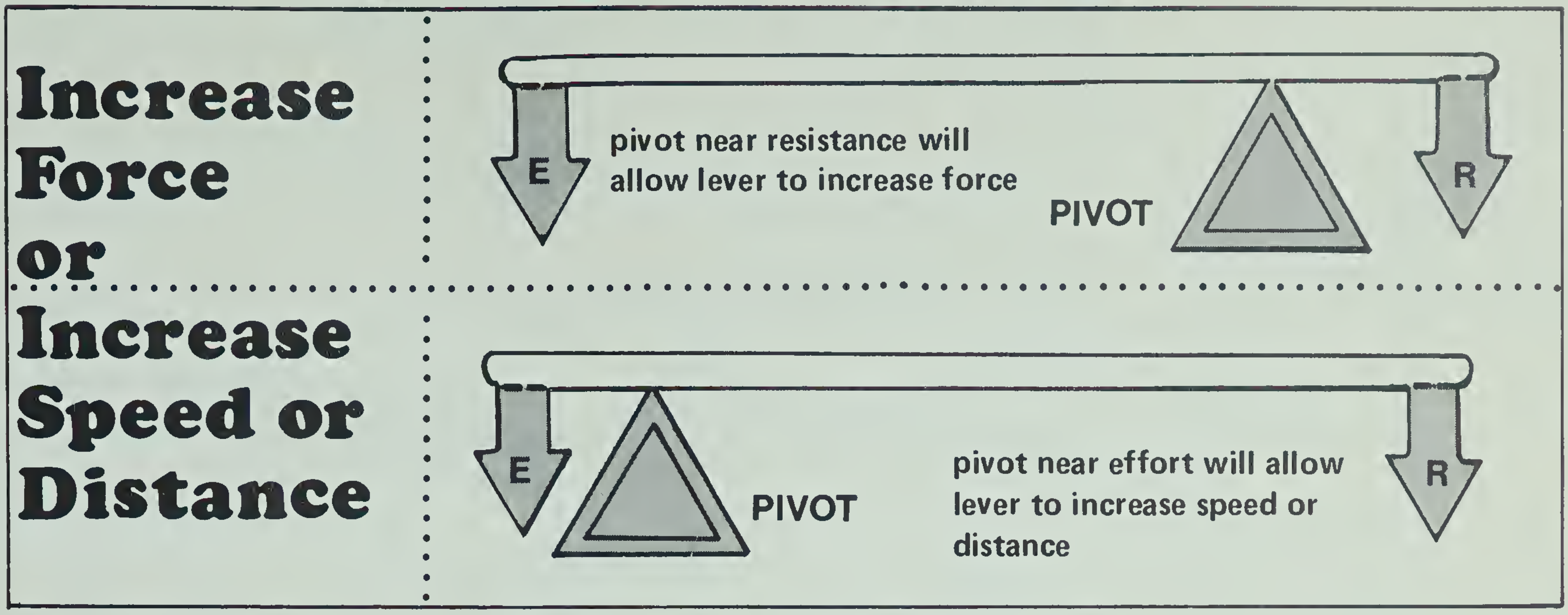
8-2. Type 1

• 8-2. In which type of lever are effort (E) and resistance (R) applied in the same direction — Type 1 or Type 2?

Let's look first at Type 1 levers. In them, effort (E) and resistance (R) are on opposite sides of the pivot (P) and are applied in the same direction.

Type 1 levers can be used in either of two ways, depending on their design. Sometimes they are used to move heavy masses by *increasing force*. That's the use shown in Figure 8-2 above. But sometimes Type 1 levers are used to move the resistance point faster or to make it travel farther (as in Figure 8-1 on page 27). Such a lever is said to *increase the speed* of the resistance point or to *increase the distance* that it moves.

TYPE 1 LEVERS CAN EITHER



• 8-3. In the lever systems shown above, what determines the kind of job the lever will do?

8-3. The location of the pivot point

Figure 8-3 below shows a Type 1 human lever aiding in the throwing of a ball.

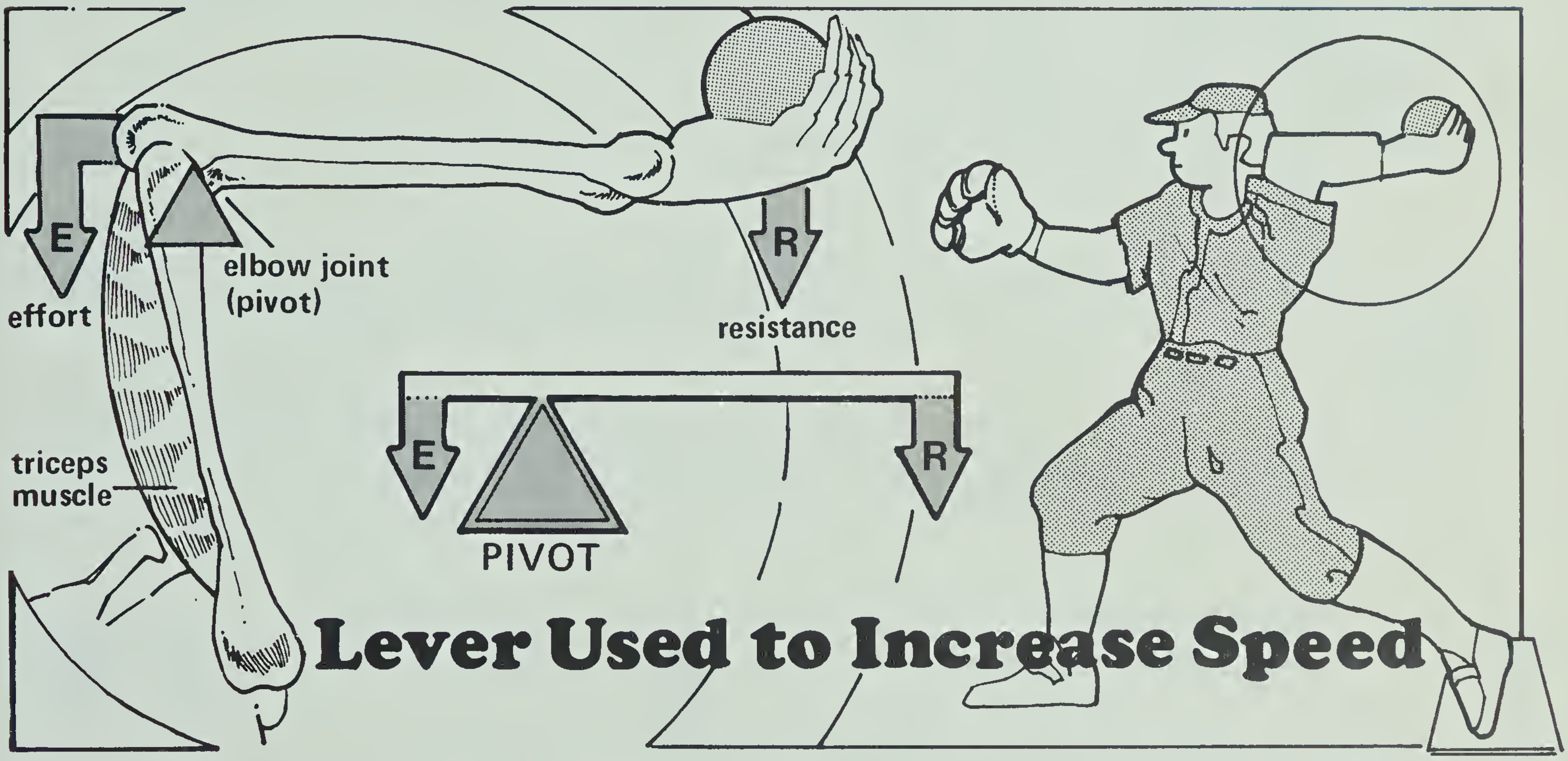


Figure 8-3

• 8-4. In Figure 8-3 above, what produces the resistance? What produces the effort? Where is the pivot?

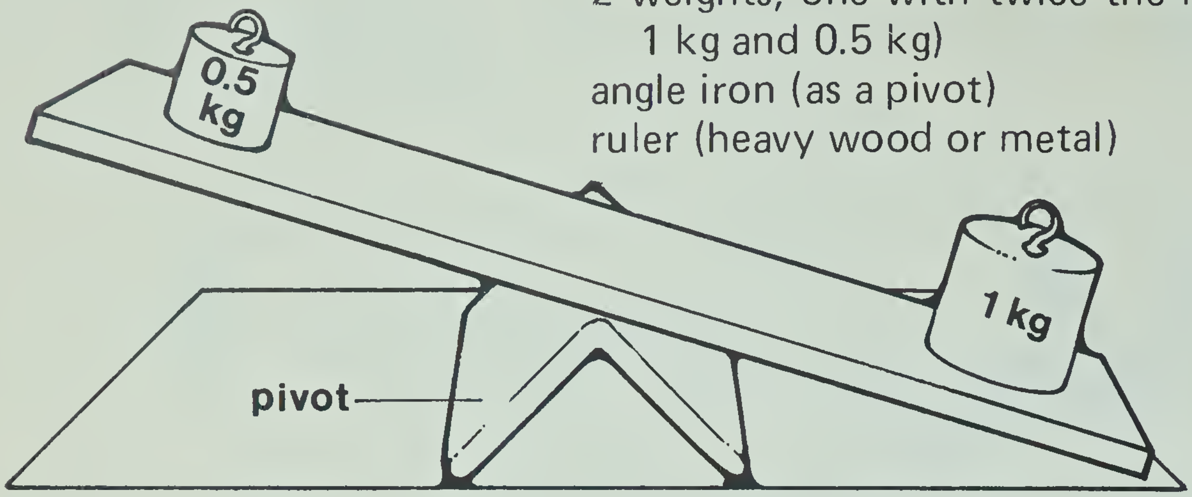
8-4. R: the weight of arm + ball; E: the arm muscles (triceps); P: at the pitcher's elbow joint

☆ 8-5. What is being increased by the body lever in Figure 8-3 above? (Hint: Look for position of pivot.)

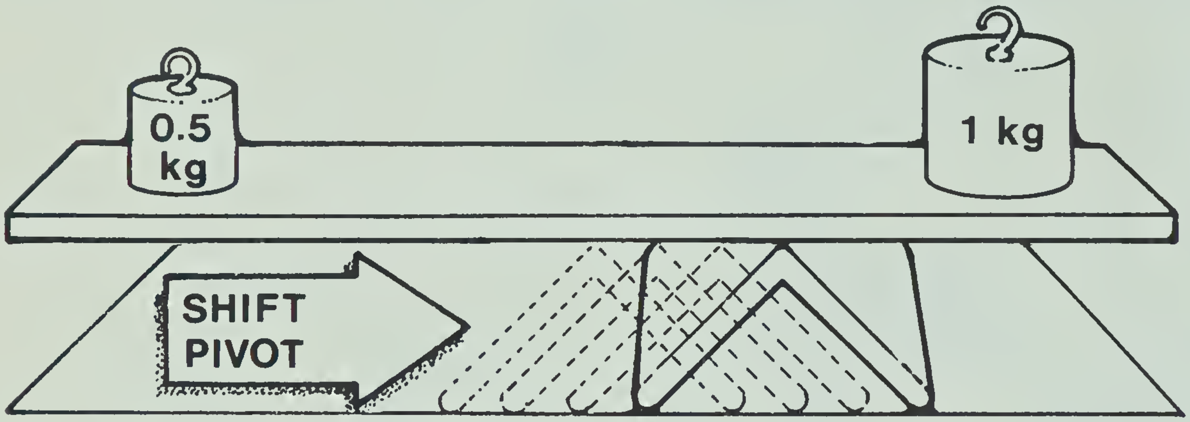
8-5. The speed of the pitcher's throw (the resistance)

See for yourself how the location of the pivot point affects the usefulness of a lever. You will need five minutes and the following materials.

2 weights, one with twice the mass of the other (for example, 1 kg and 0.5 kg)
angle iron (as a pivot)
ruler (heavy wood or metal)



A. Place the weights at each end of the ruler, with the pivot at the center.

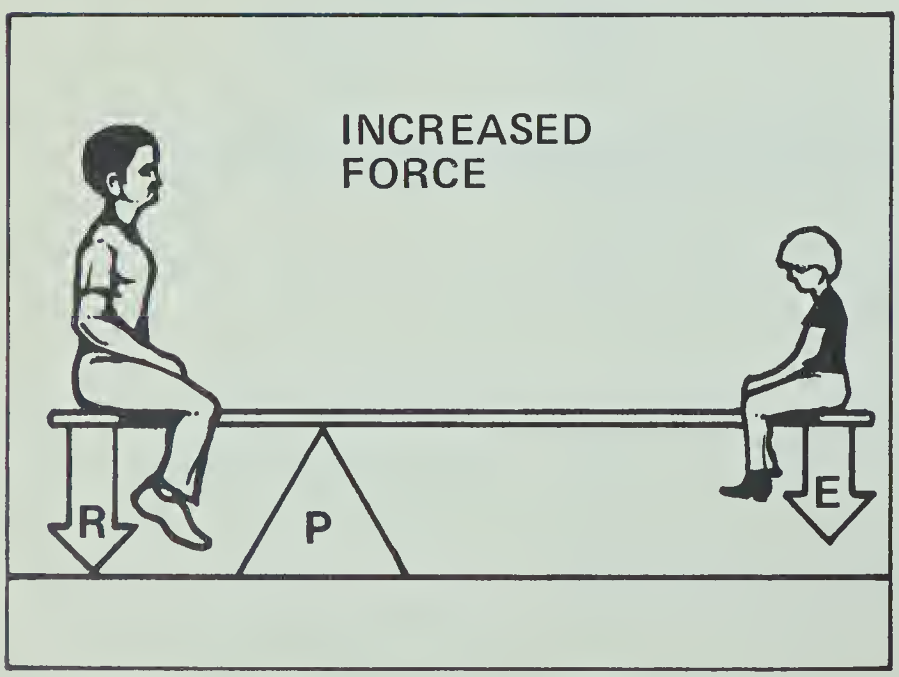


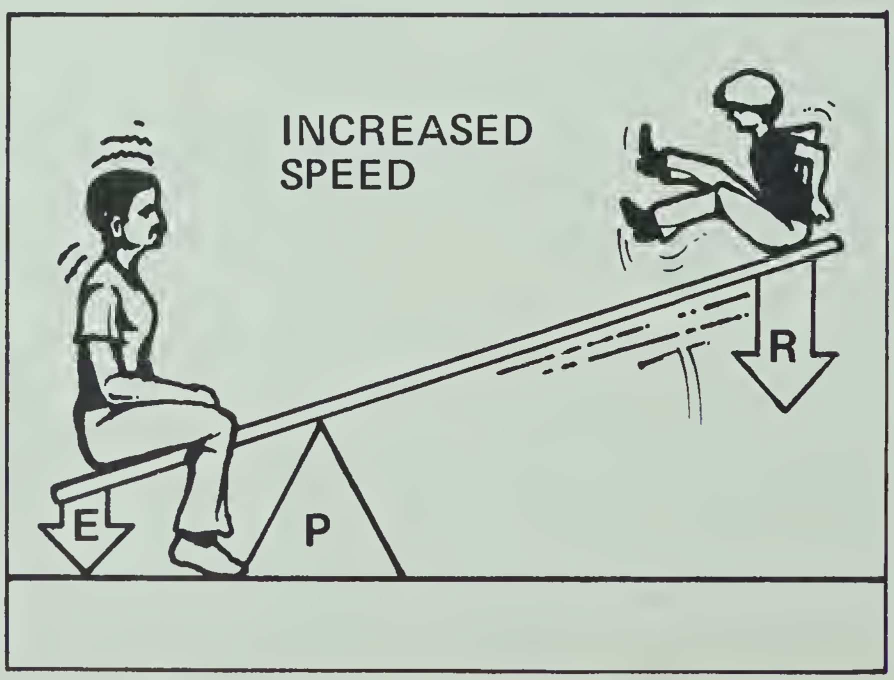
B. Shift the pivot point toward the heavier weight, 1 cm at a time. (Don't move the weights — move the pivot.)

8-6. The lighter weight lifts the heavier weight.

● 8-6. What happens when the pivot approaches the heavier weight?

Without adding extra weight you were able to lift the heavier weight. You simply moved the pivot point.





From the illustrations at the bottom of the previous page, you can see that the position of the resistance and the effort can be switched. This type of lever changes from one that increases force at the resistance to one that either increases speed at the resistance or the distance that the resistance point moves.

• 8-7. Which direction should you move a pivot point on a Type 1 lever to increase the weight lifted with the same effort?

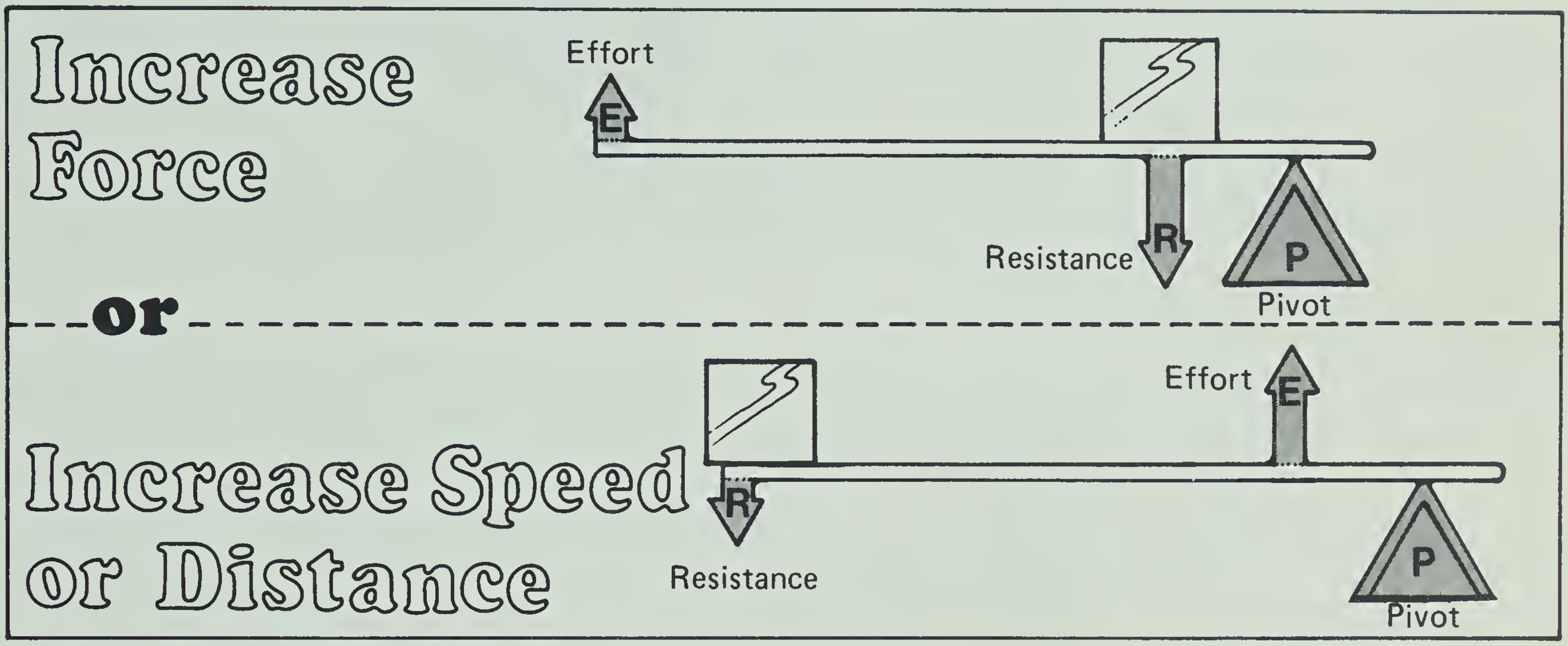
8-7. Closer to the object being lifted (toward the resistance)

• 8-8. Which direction should you move the pivot of a Type 1 lever if you want to increase the speed with which an object is lifted, or the distance it is lifted?

8-8. Away from the object being lifted (toward the effort)

With Type 2 levers, resistance and effort are on the *same side* of the pivot but are applied to the lever arm in *opposite directions*. Type 2 levers operate in either of two ways.

Type 2 levers include both the Class 2 lever with the resistance between pivot and effort and the Class 3 lever, with effort between pivot and resistance.



• 8-9. When the effort point is located between the pivot and resistance points, what increases?

8-9. Speed or distance

• 8-10. When the resistance point is located between the pivot and effort points, what increases?

8-10. Force

☆ **8-11. In your own words give two reasons why levers are useful.**

8-11. They can be used to increase speed or distance; they can be used to increase force.

But where in your body do you have anything that looks like these different levers? You may not readily recognize your body's levers, but they are there. Any movable joint can be a pivot point. A muscle pulling on a bone creates effort. The weight of a body part, plus whatever you are pulling on or lifting, produces resistance. Look at Figure 8-4 on page 32.

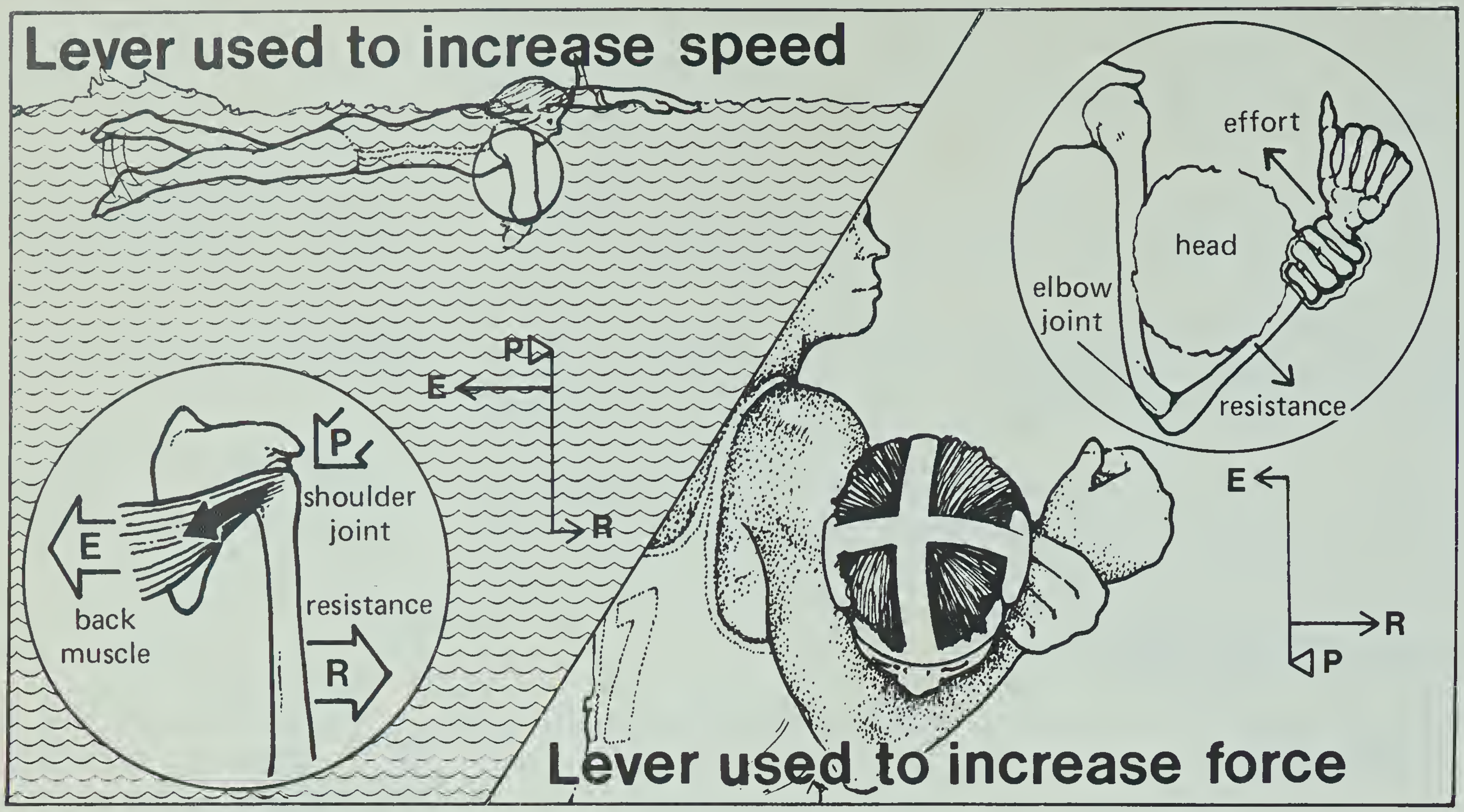


Figure 8-4

8-12. R: swimmer, water — wrestler, opponent's head; E: swimmer, back muscles — wrestler, arm muscles and other hand

● 8-12. In Figure 8-4 above, what produces resistance for the swimmer? For the wrestler? What produces effort for the swimmer? For the wrestler?

8-13. Pivot point: swimmer, shoulder joint — wrestler, elbow joint

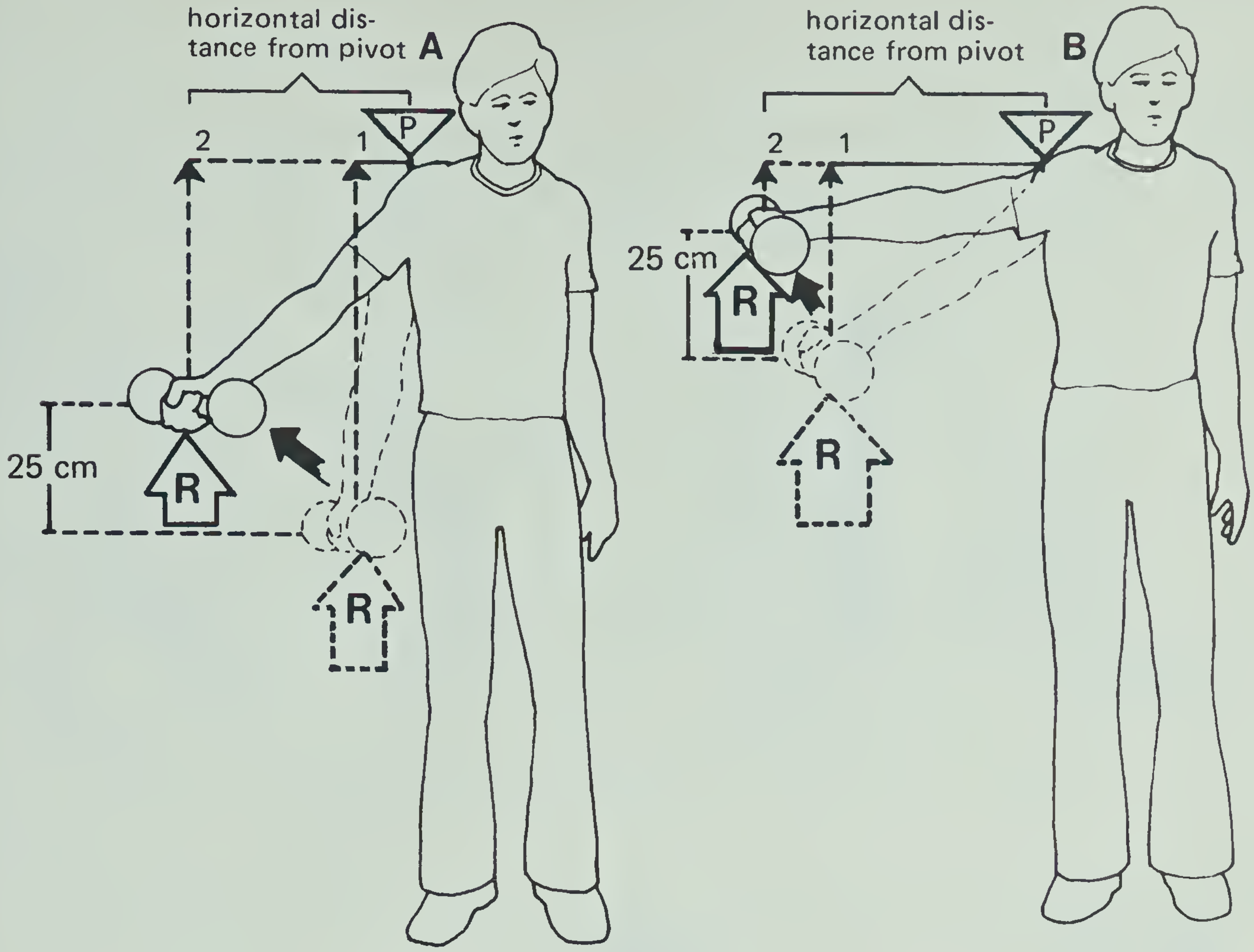
● 8-13. In Figure 8-4 above, what is the pivot point for the swimmer? For the wrestler?

Most body levers are constructed to increase speed or distance. They have the effort (muscle) between the pivot (joint) and the resistance (extremity). Even so, such levers can be used to transfer force, if that is the athlete's main concern. The weight lifter shown on the left provides an example.

She needs to minimize the amount of effort it takes to lift the weight — to make her lift as efficient as it can be. As a lever, her lower arm favors speed. Nevertheless, she can help it to transfer force by making sure to keep resistance and pivot as close together as possible.

Look at Figure 8-5 on page 33. The shorter the horizontal distance between resistance and pivot, the less effort needed for a given resistance. You can prove this for yourself. Try to lift a straight chair with one arm. Do it first with outstretched arm, then again with arm close to your side. Which way is easier?

When this boy lifts the dumbbell, he keeps his elbow locked. This means the effort remains at the muslces of his upper arm. As his arm rises, the resistance moves farther and farther from the pivot.



A. He raises the dumbbell 25 cm (from 1 to 2) with moderate effort. Resistance starts at little horizontal distance (1) from pivot.

B. He raises it another 25 cm (from 1 to 2) only with great effort. Resistance starts at considerable horizontal distance (1) from pivot.

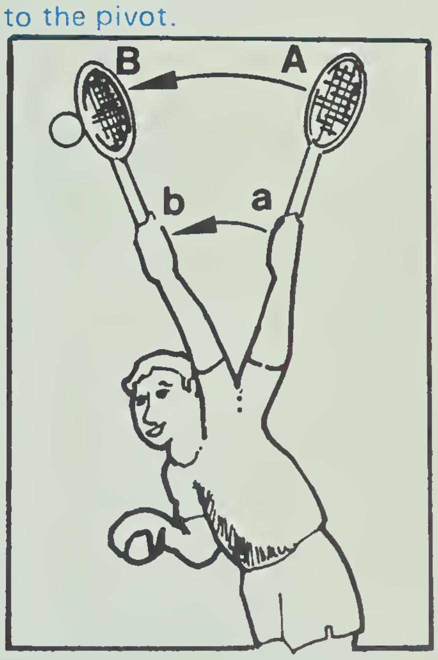
Figure 8-5

● 8-14. What did the girl weight lifter on the preceding page do to make the weight easier to lift?

8-14. She moved the weight closer to the pivot.

As useful as your body's levers are, some of them can be made more effective. Most of the implements used to hit balls are simply extensions of your own levers. Look at this tennis player. His arm and racket together form a long lever. His shoulder joint is the pivot. The effort is provided by the muscles of the arm and the body. The major effort is used to speed up the racket. With a faster swing, the ball can be hit with greater force. Imagine how much slower the ball would move if the racket were much shorter.

During a serve his hand moves from Point a to Point b. In the same amount of time the racket moves from Point A to Point B.

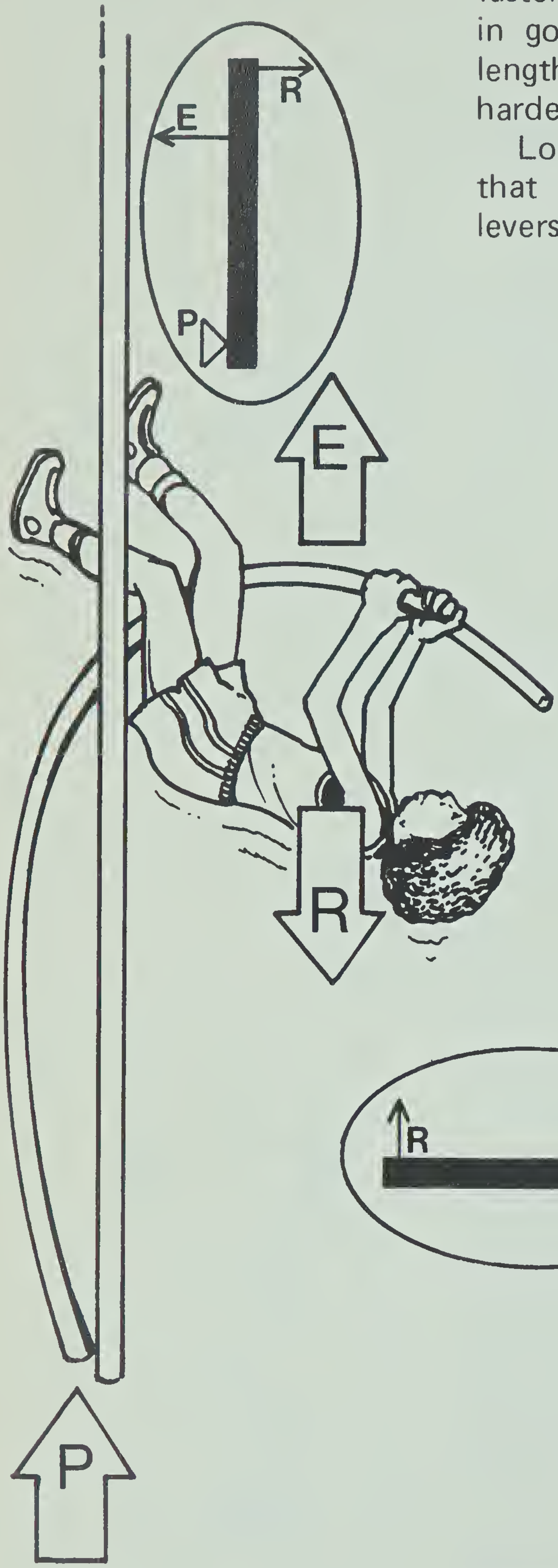


● 8-15. When you make a tennis serve, which moves faster, your hand or the head of your racket?

8-15. The head of your racket; because it moves farther in the same amount of time.

Since your racket moves a greater distance, it must be moving faster than your hand. Thus the racket can make the ball move faster than your hand alone could. Something similar happens in golf or baseball. By using a golf club or baseball bat you lengthen the levers in your body. This helps you hit the ball harder, faster, and farther.

Look at Figure 8-6 below. It shows some other sports levers that help the athlete. Although not extensions of your body levers, they are used to transfer force from your muscles.



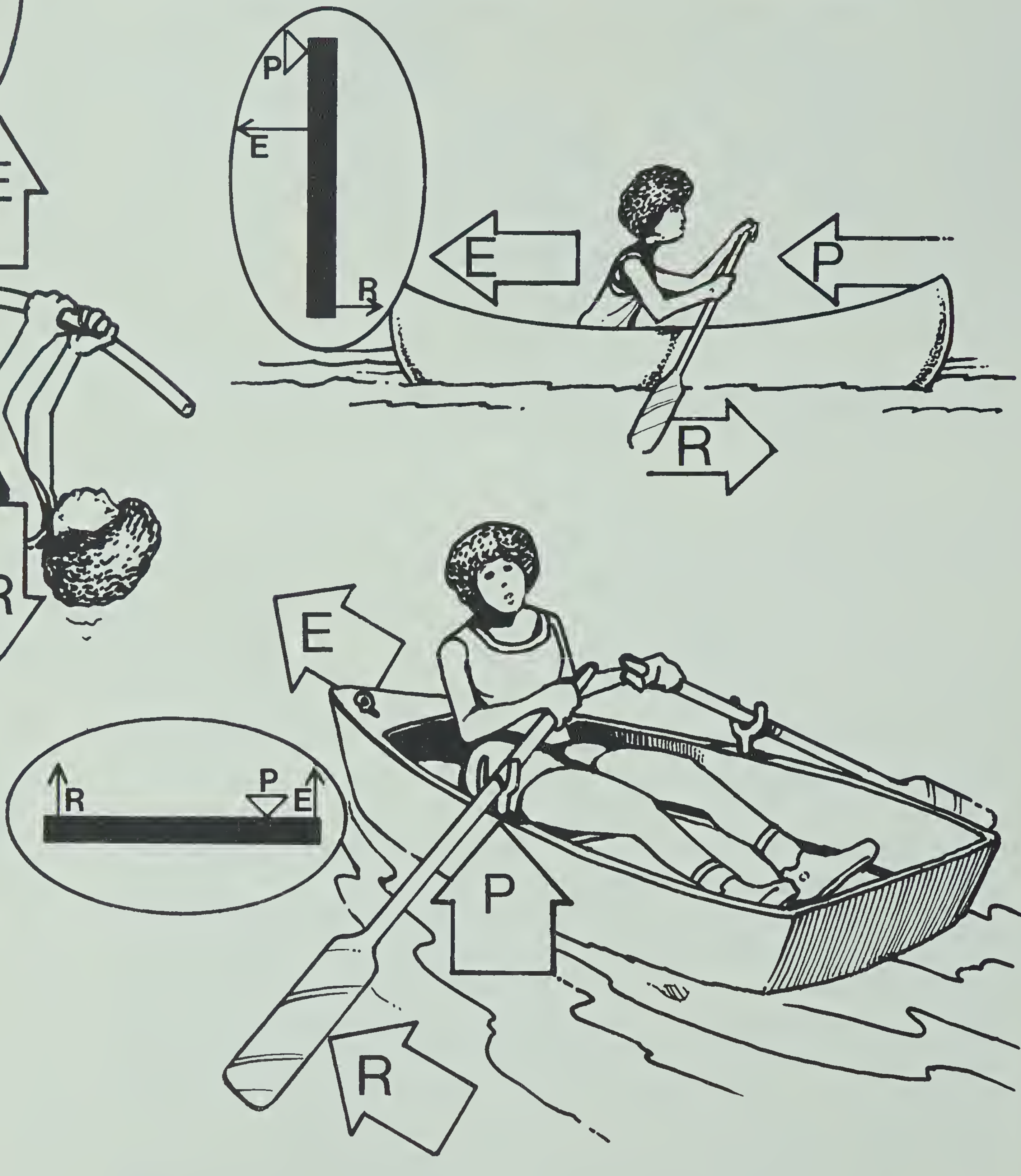


Figure 8-6

8-16. To increase the lever arm so that a ball can be hit harder, faster, or farther

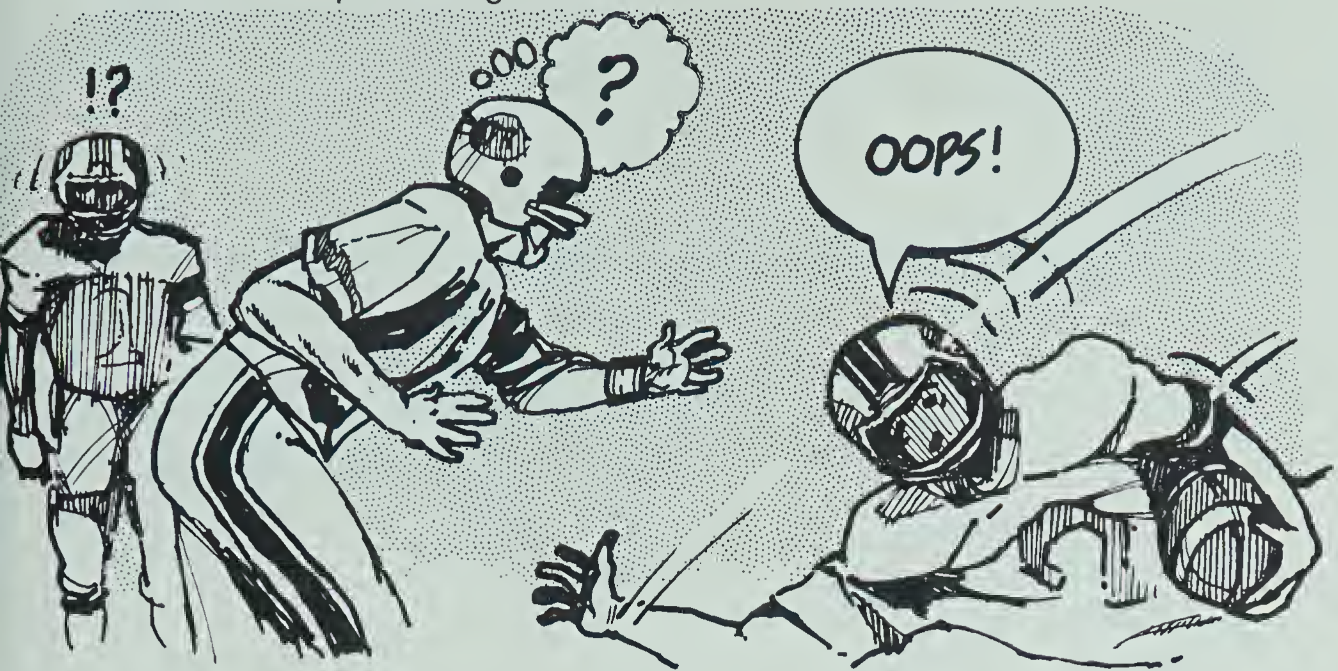
☆ **8-16. Why are bats, clubs, and rackets used in sports?**

ACTIVITY 9: BALANCE

ACTIVITY EMPHASIS: For a body to remain stable, its center of mass must remain as low as possible and vertically within the base of support.

MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter. See "Advance Preparations" in ATE front matter.

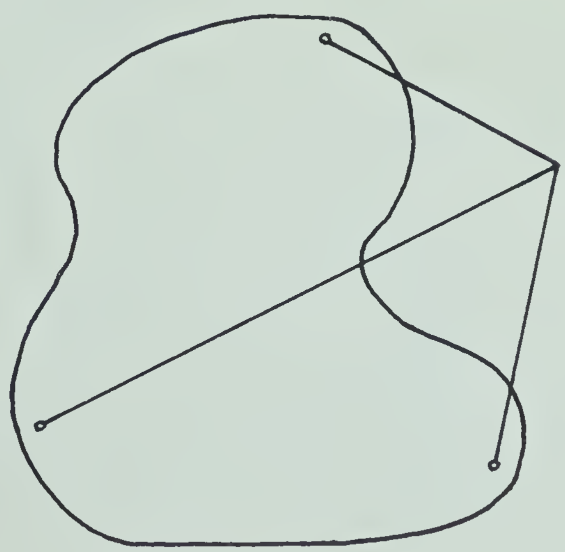
Good balance is important in sports, whether you are standing still or moving. Imagine how hard it would be to do well in gymnastics or football, for example, if you were always off balance and kept falling down!



In this activity you will read about three important principles that can help you stay in balance. They will keep you on top of things.

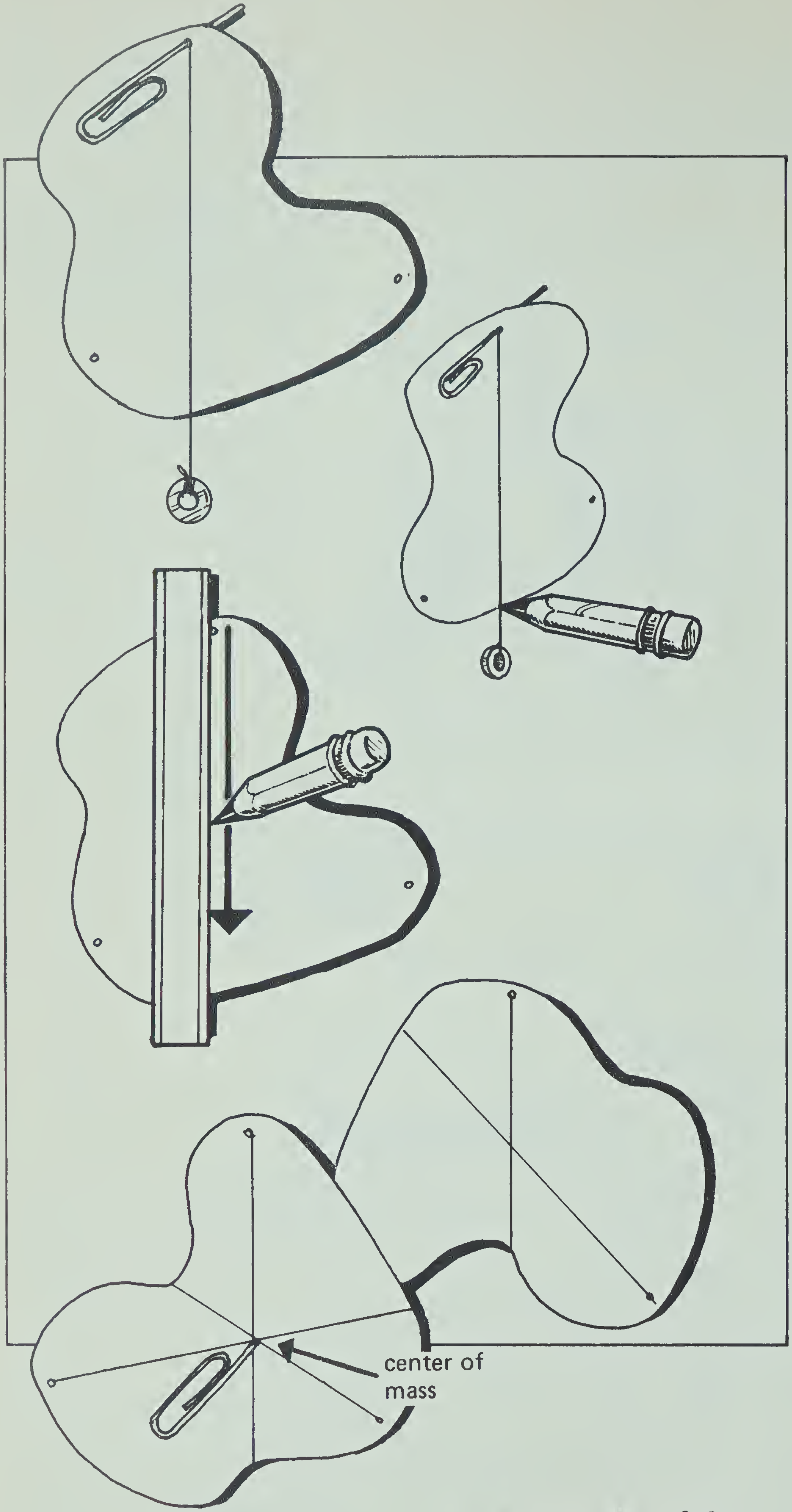
Does an object have a point where it will always balance? To find out you will need fifteen minutes and the following materials.

- scissors
- piece of heavy cardboard, irregular in shape, largest dimension about 25 cm across
- paper clip
- length of string 30 cm long
- washer (or sinker)
- ruler
- needle or pin



three holes within 0.5 cm of edge

A. Use a needle or pin to poke holes close to the edge of the cardboard in three widely separated places. The holes should be within 0.5 cm of the edge.



B. Straighten the paper clip part way. Tie one end of the string to the washer. Tie the other end around the straightened paper clip. Then stick the paper clip through one of the holes as shown.

C. Hold the paperclip so that the cardboard and string dangle vertically as shown. Then mark the bottom of the card where the string touches once the washer and card come to rest.

D. Use the ruler to make a straight line to your mark from the hole that the paper clip went through.

E. Repeat the process in Steps B, C, and D for the other two holes. Now your cardboard should have on it three lines that cross at a point (or form a tiny triangle). Label this point *center of mass.* Poke your paper clip through the point. Let the cardboard balance on the paper clip.

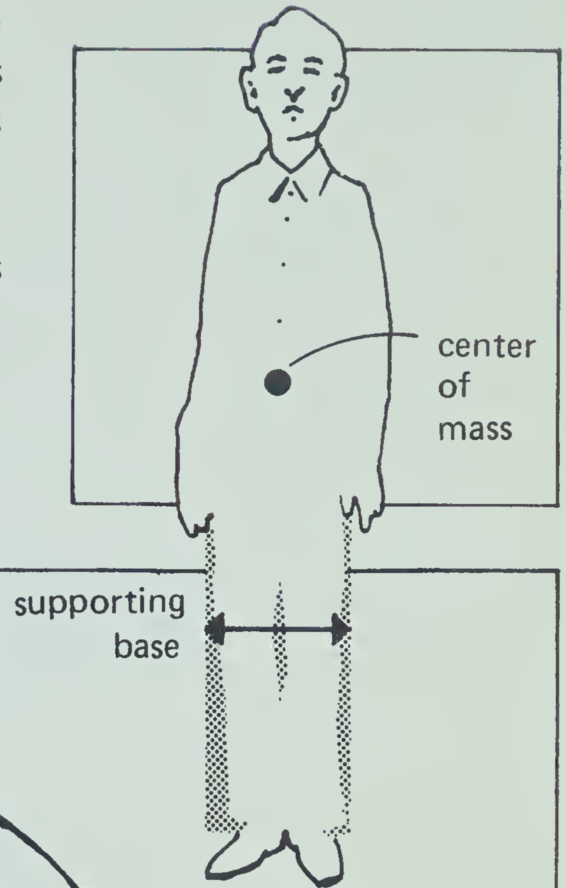
● 9-1. Does the cardboard piece balance on the paper clip as shown in Step E, *no matter what side or corner is uppermost*?

9-1. Yes

● 9-2. Can any of the other three holes be used to balance the cardboard *in any position*?

9-2. No

There is an imaginary point about which any object can be suspended in perfect balance. You might think of this point as the one at which the weight of the body is concentrated. This point is called the *center of mass.*



Principle 1: A body is balanced only when its center of mass is vertically within its supporting base.

Any object, living or not, has a center of mass. This center can change as the object moves or shifts position. Look at Figure 9-1 below.

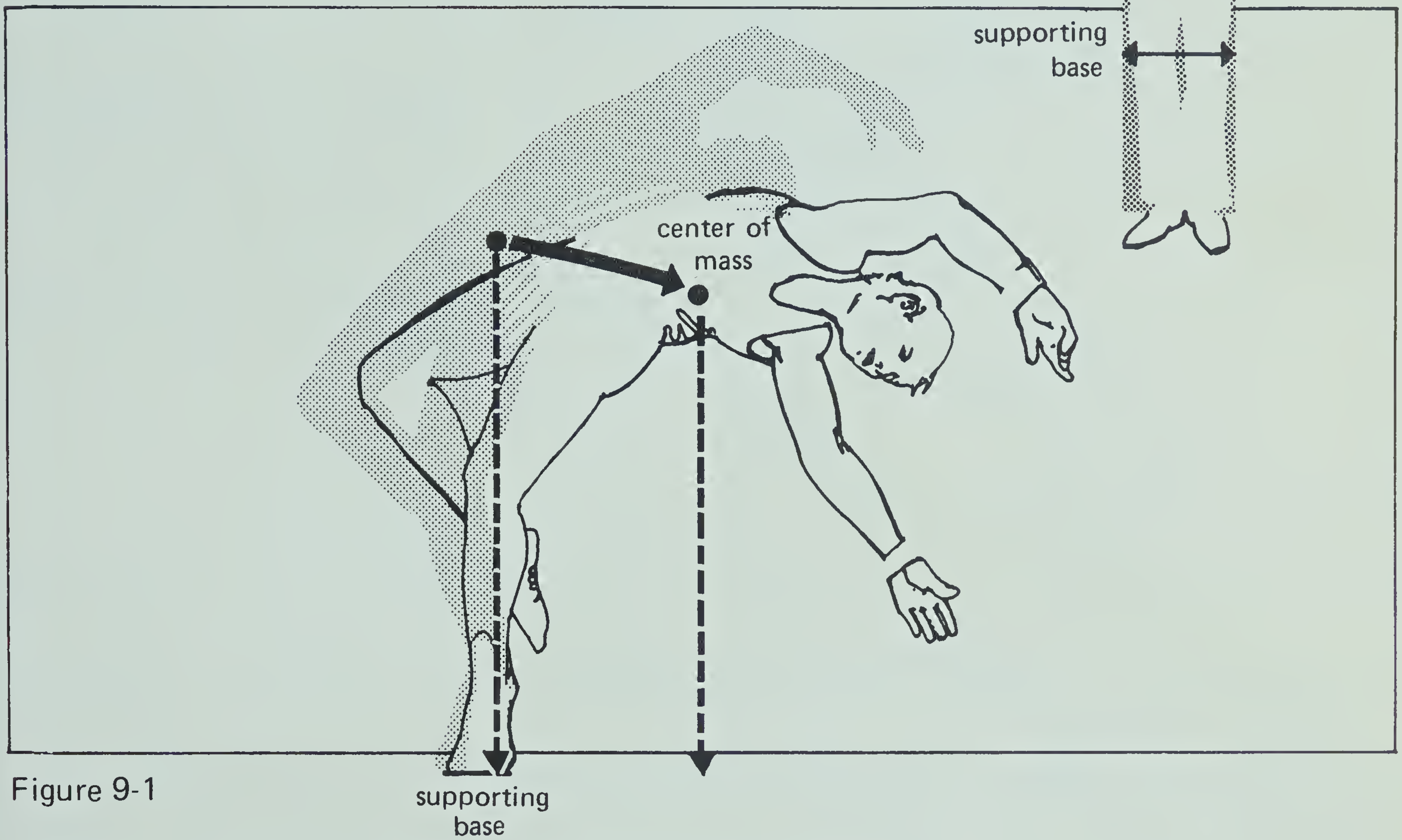
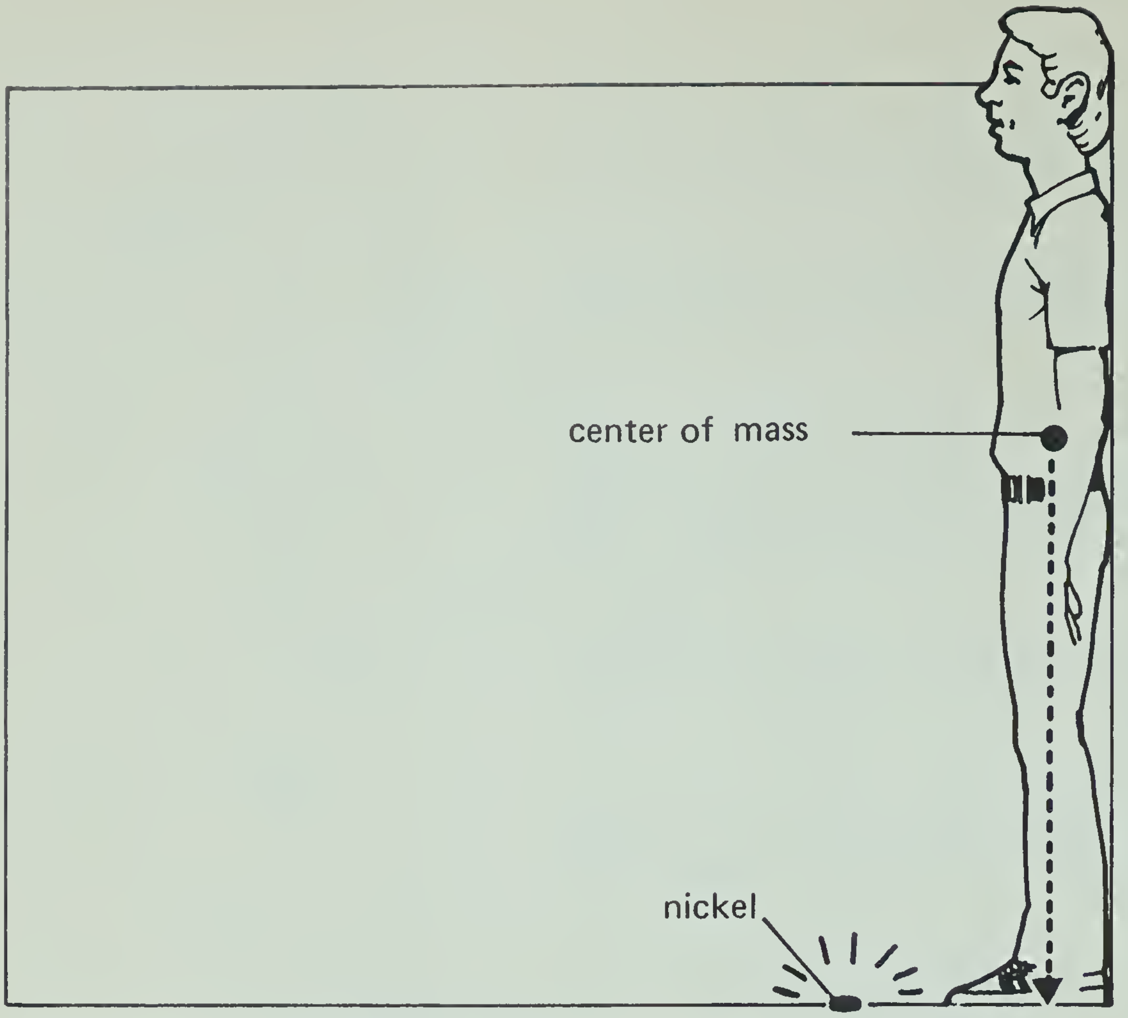


Figure 9-1

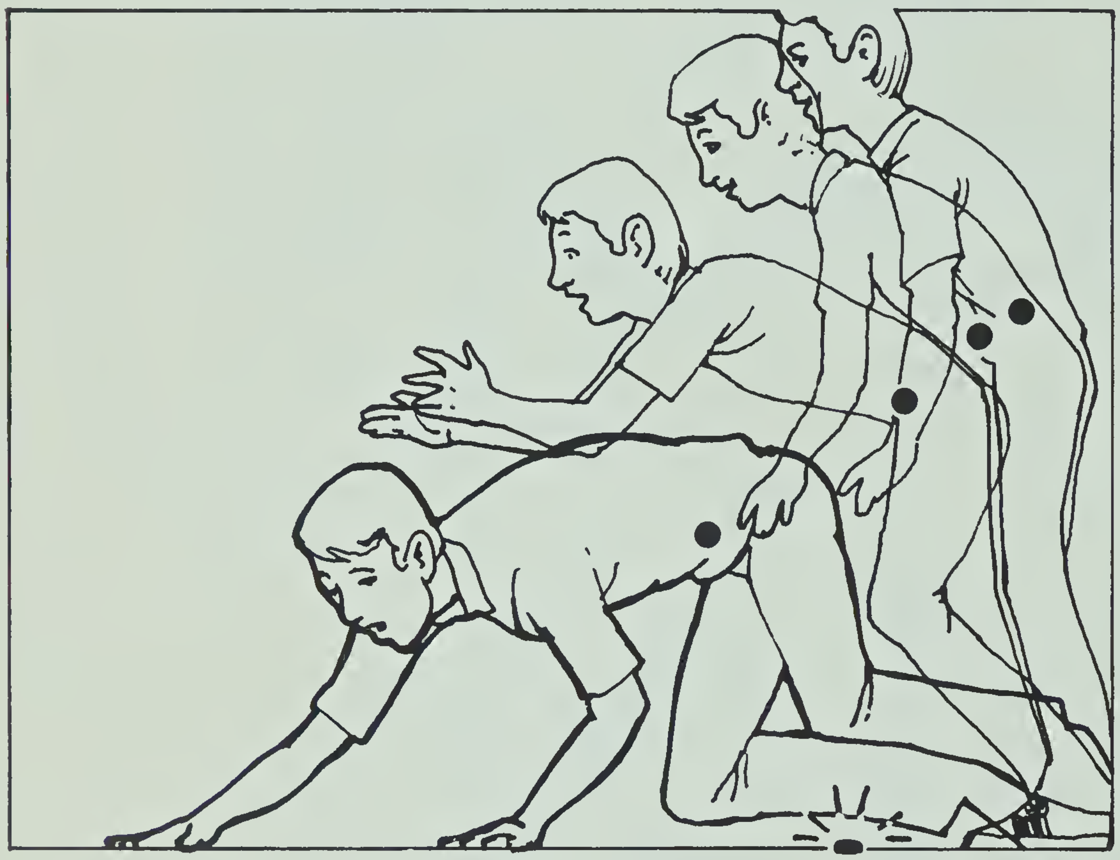
Figure 9-1 above shows what is necessary for balance. A vertical line through your center of mass must fall within your *supporting base.* If the line falls outside your base of support, over you go!

To see how your center of mass changes as you move, and what this does to your balance, try the following activity.

A male partner is specified because most females have centers of mass so low as to enable them to perform the task.



A. Ask a male student to stand as shown — with his back to a wall and his heels touching the wall. Put a nickel on the floor a few inches out from his toes.



B. Tell your partner that he may have the nickel by simply bending over and picking it up. But say no fair bending the knees, moving the feet, or losing balance. (Don't worry about your nickel — it's safe.)

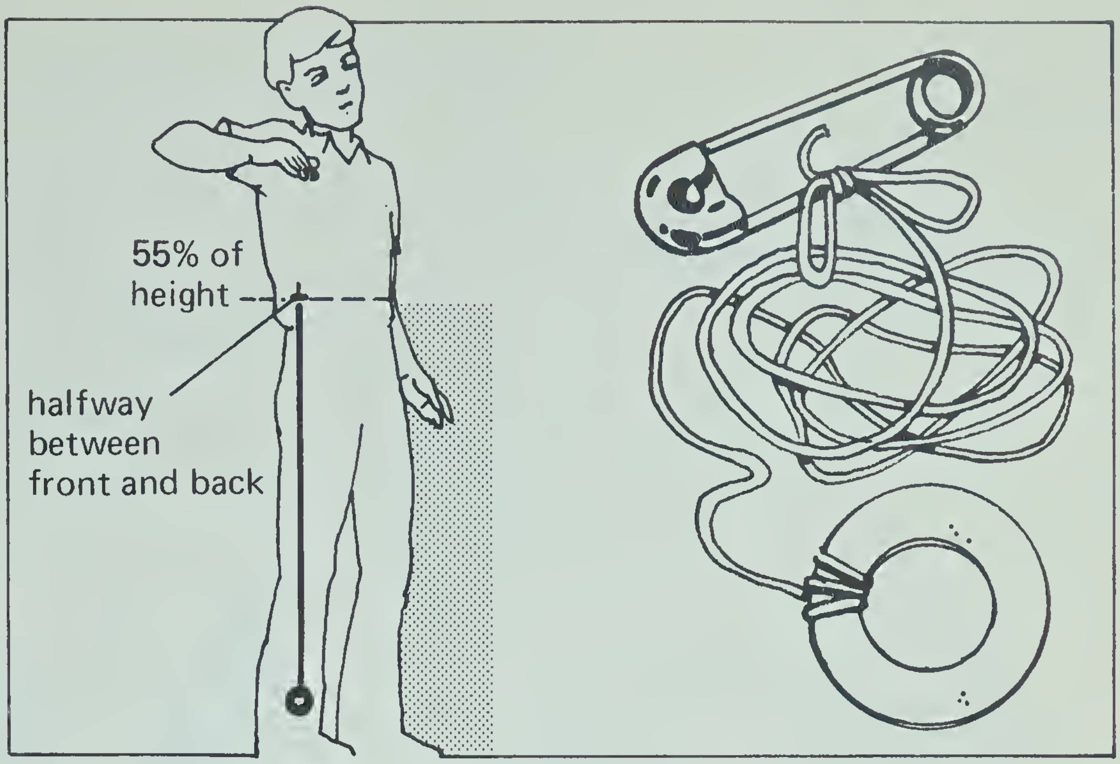
9-3. It was lost. Partner's center of mass was no longer over the base of support.

● 9-3. What happened to your partner's balance when he tried to pick up the nickel? Why?

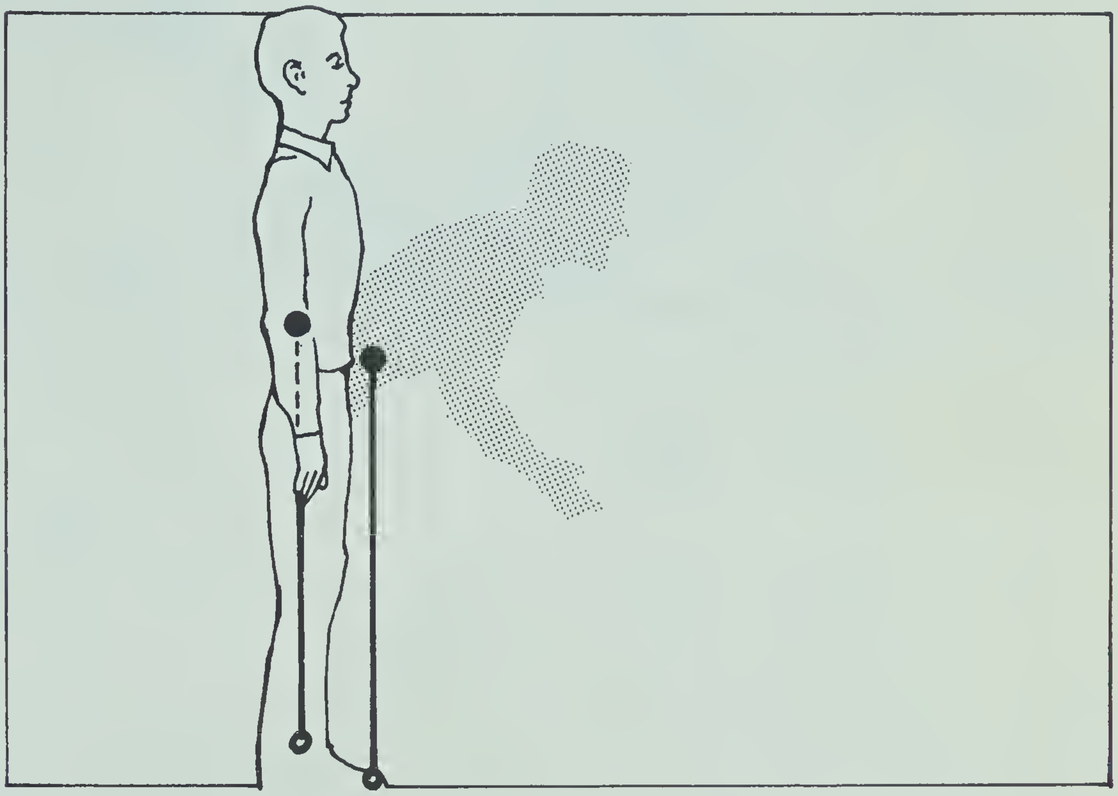
To see exactly what happened to your partner's center of mass, try this. You will need the following materials.

washer (or sinker)
length of string 120 cm long
safety pin

A. Tie the washer to one end of the string. Then pin the other end to your partner's clothing at the place shown. The weight should hang about 6 to 8 cm off the floor when he stands erect.



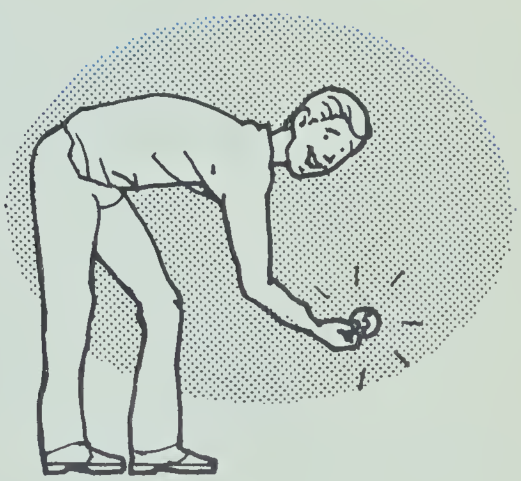
B. Now ask your partner to stand against the wall as before. Tell him to reach for the nickel again. Watch what happens to the washer as he bends forward.



● 9-4. Where was the washer as your partner began to lose his balance?

9-4. In front of his feet (his base of support)

Principle 2: The larger your base of support, the more stable your body.



Increasing the size of your base of support will increase your stability. Even just lengthening the base in one direction increases stability in that same direction. In the above activity, your partner's forward balance can be improved by the simple act of putting one foot in front of the other, heel-to-toe. This extends his base of support forward.

Call off the bet!

Now let your partner try to pick up the nickel. Watch.

9-5. It swung forward but did not pass the base of support.

• 9-5. Describe what happened to the washer on the string.

9-6. Base of support was lengthened, so the center of mass did not extend beyond it.

• 9-6. Why was your partner successful at reaching the nickel this time?

This principle of stability is used frequently in sports. Look at Figure 9-2 below. The three football players are in position prior to the snap of the ball. Try it for yourself. Get into each of these positions and see which one requires the hardest push to move you.

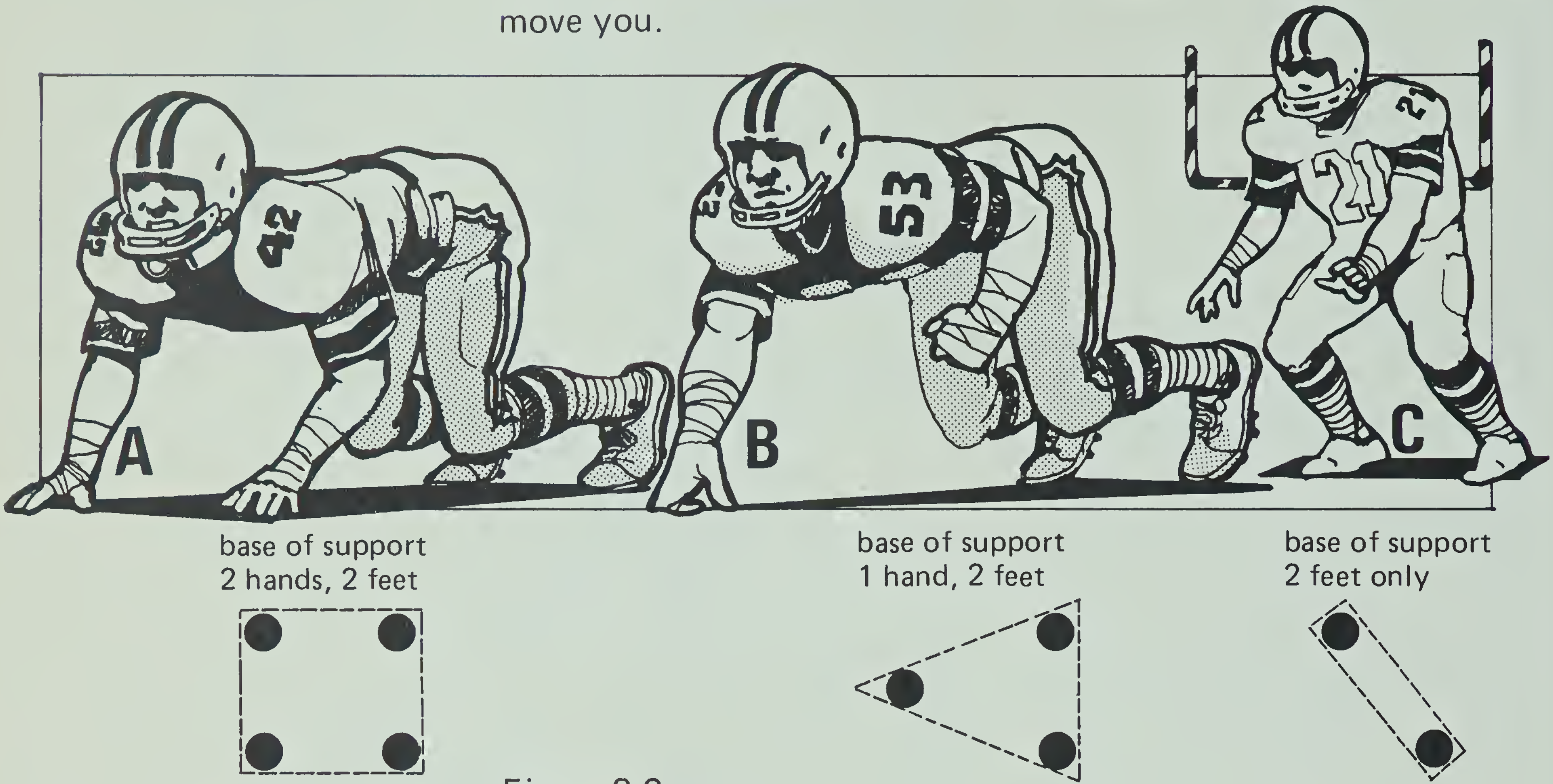


Figure 9-2

9-7. A is most stable because it gives the largest base of support; C is least stable because it gives the smallest base of support.

• 9-7. Of the three positions in Figure 9-2 above, which is most stable? Least stable? Why?

By having a larger base of support you are more stable. But in some sports you get penalized for that. In many gymnastic routines the object is to stay in balance despite having only a small base of support. This is hard to do, and that's why a person who is successful scores highly.

9-8. Her left foot; yes

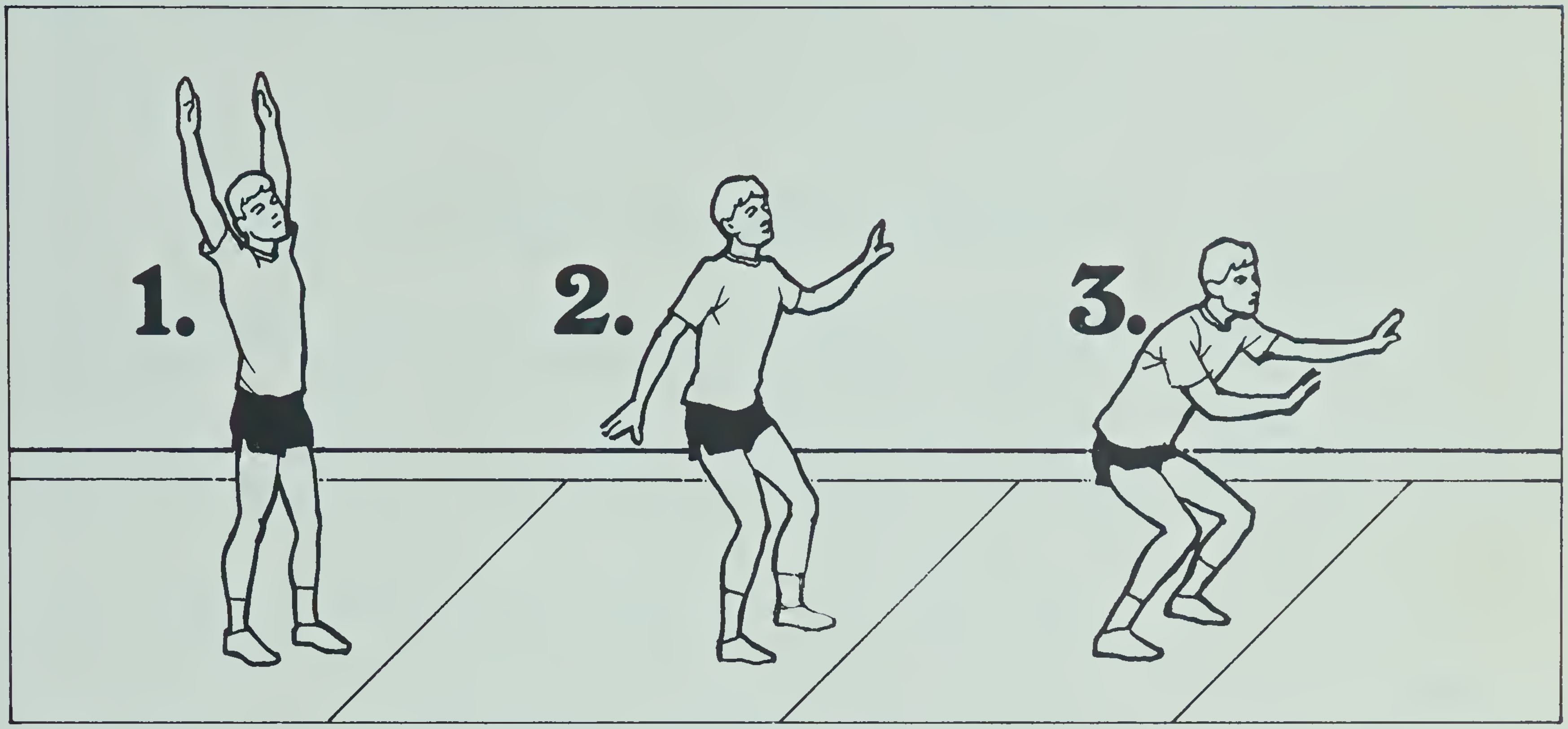
• 9-8. What is the base of support of the gymnast shown above? Is she liable to score high on this figure?

Principle 3: The lower your center of mass, the more stable your body.

As you move, your center of mass changes. If you raise your arms, your center of mass shifts upward, and you become less stable. If you crouch, your center of mass shifts downward, and your stability increases.

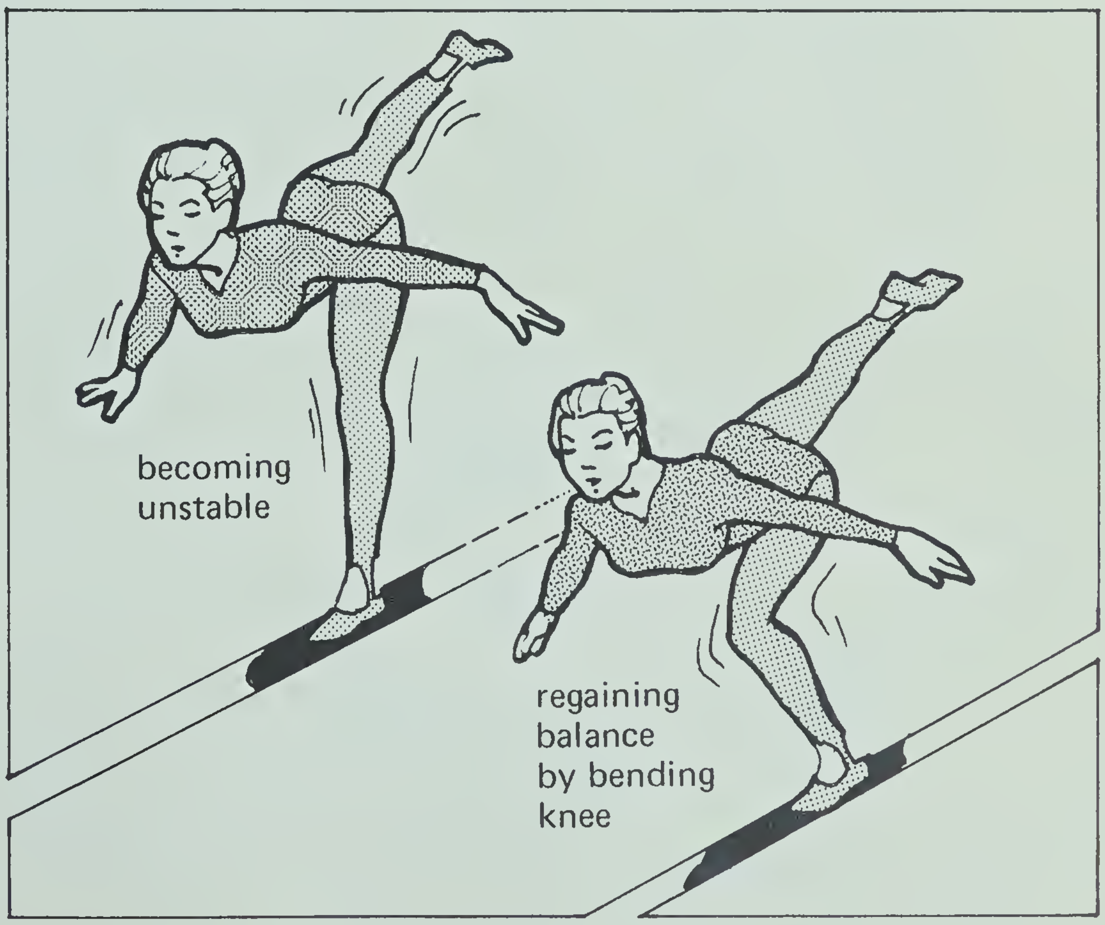
☆ **9-9. Rank the following defensive sports positions in order from the most to the least stable.**

9-9. Most stable, 3; least stable, 1



Now see for yourself. Get a friend and check his or her stability in each of the three positions. Without overdoing it, push on your partner's shoulders. See which positions are the most and least stable. Was your ranking correct?

Principle 3 is often used in gymnastics and modern dance. If performers begin to lose their balance they assume a semi-crouching position to become more stable. Football players also lower their center of mass by crouching before they make contact with an oncoming blocker or tackler.



9-10. Drop into a semi-crouching position to regain it.

9-11. To be more stable

9-12. 1 – A body is balanced only when its center of mass is over its supporting base; 2 – The larger your base of support, the more stable your body; 3 – The lower your center of mass, the more stable your body.

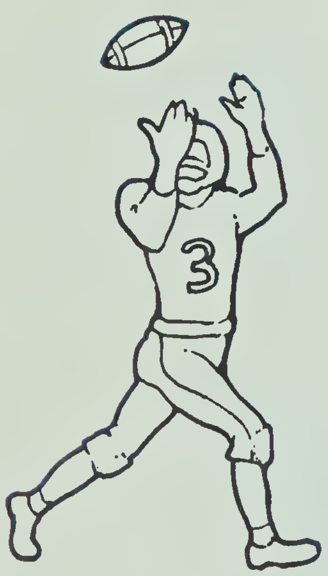
● 9-10. If you begin to lose your balance during a gymnastics routine, what should you do?

● 9-11. What is one reason that so many football players lower their bodies before making blocks?

☆ **9-12. What are the three principles that affect a person's stability?**

ACTIVITY EMPHASIS: Momentum may be more easily absorbed by lengthening the time of impact and/or by increasing the contact area to reduce pressure.

MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter.



ACTIVITY 10: STOPPING OBJECTS

Some years ago, when wide receiver Lance Alworth was catching passes for pro football's San Diego Chargers, he was said to have the "softest hands" in the game. That didn't imply he lacked calluses. It meant that he pulled the ball in so smoothly that you couldn't tell exactly when it first touched his hands. He dropped very few passes.

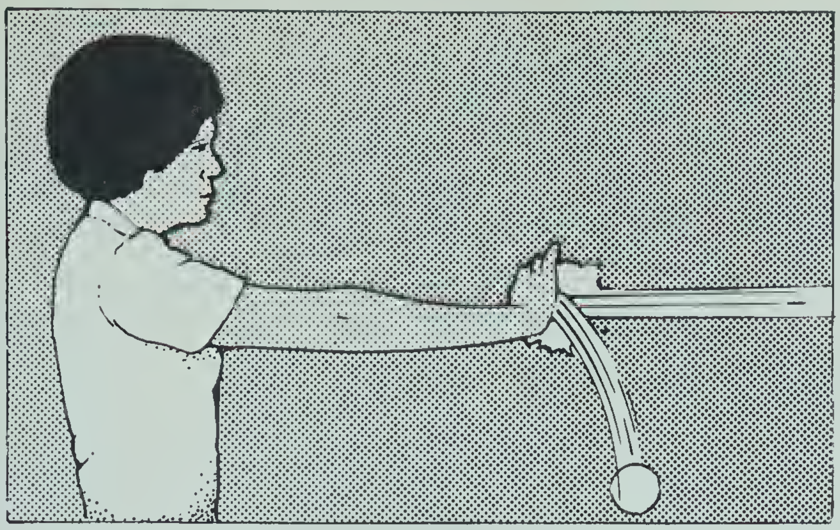
Another National Football League pass receiver of the same period was known to his teammates as "Old Iron Hands." They said of him, unkindly, that he couldn't catch a cold if he spent New Year's Eve at the North Pole in a bikini.

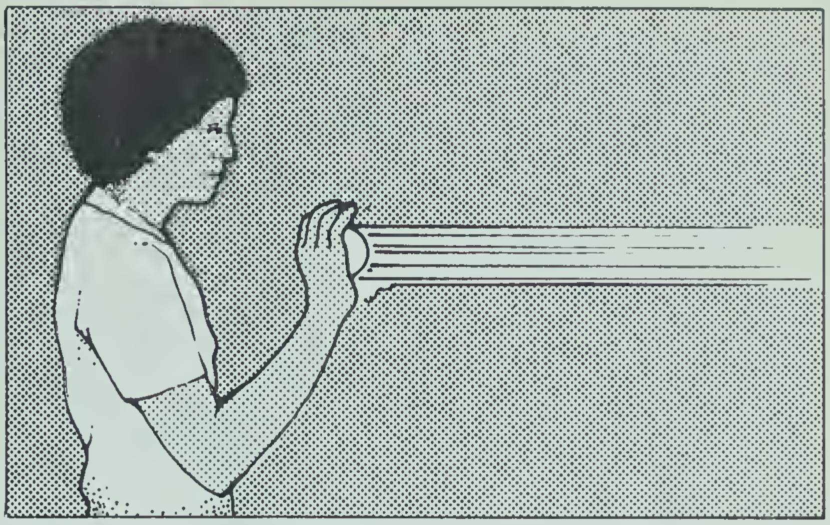
In sports like football, baseball, and basketball, catching the ball cleanly can be very important. What technique do the successful players use? What can you do to improve the way you catch? To answer these questions, you need to know something about *force* and about *pressure*.

It turns out that the same facts about force and pressure that apply to things that contact you (like baseballs and footballs) also apply to things that you contact (like the hard ground). So in this activity you can also find out how gymnasts and other athletes try to avoid injury when they fall or slide.

FORCE

If you try to catch a tennis ball one-handed with your arm stiff, the ball is likely to bounce off your hand. But if you flex or bend your elbow as the ball reaches you, you will have much less trouble. Try it. You should find that "giving" with the ball improves your chances of catching it cleanly.





Here's what happens. When you flex your elbow, you increase the amount of time that the ball is pushing into your hand (the *period of impact*). Increasing the period of impact does two things. It gives your hand more time to close around the ball. And, more importantly, it reduces the force of the ball striking your hand.

The principle is this: if you increase the time — or distance — over which an object's impact is absorbed, you decrease the force of that impact. As a result, the ball (1) doesn't smack into your hand so hard, and (2) doesn't bounce off your palm so fast. Both these changes make the ball easier to catch.

The moving ball's momentum can be expressed in terms of impulse (force X time) or as momentum (mass X velocity). Thus Ft = mv, and F = mv/t. Furthermore, force X distance = ½ mass X velocity-squared, and $F = \frac{1}{2}mv^2/d$. Therefore, force varies inversely with either time or distance.

● 10-1. Think of catching a raw egg thrown toward you. What should you do to keep the egg from breaking as it hits your hands?

10-1. "Give" with your arms.

☆ **10-2. Why is it easier to catch a fast-moving ball if you "give" when it hits your hands?**

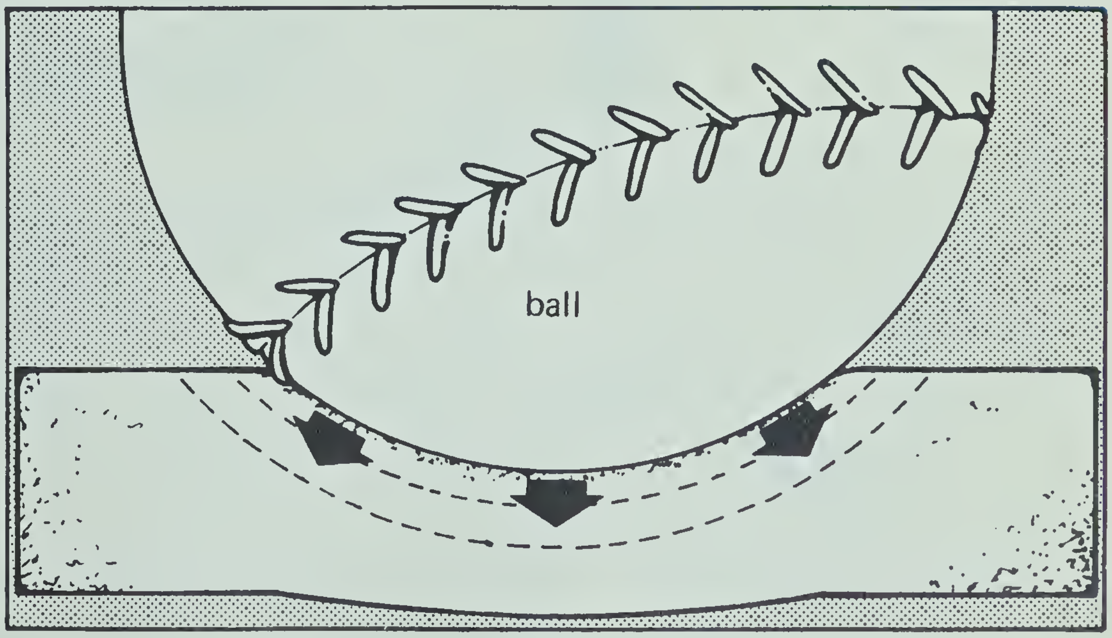
10-2. The impact of the ball is spread over a longer time, so the force is less. Also, you have more time to grab the ball.

● 10-3. What would probably happen if you kept your arms stiff and tried to catch a fast-moving ball?

10-3. The ball would probably bounce off your hands after stinging them.

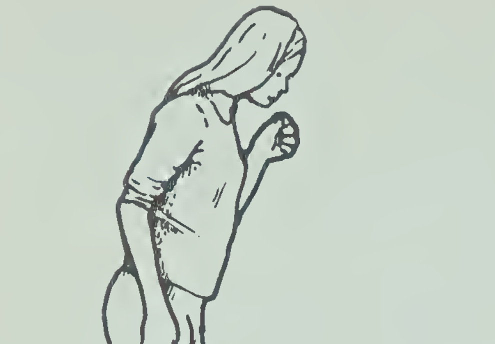
Sometimes baseball players apply the reduction-of-force principle in another way. They put a small piece of sponge rubber in their glove. This cushions the impact, since the ball sinks into the sponge and exerts its force over a longer time.

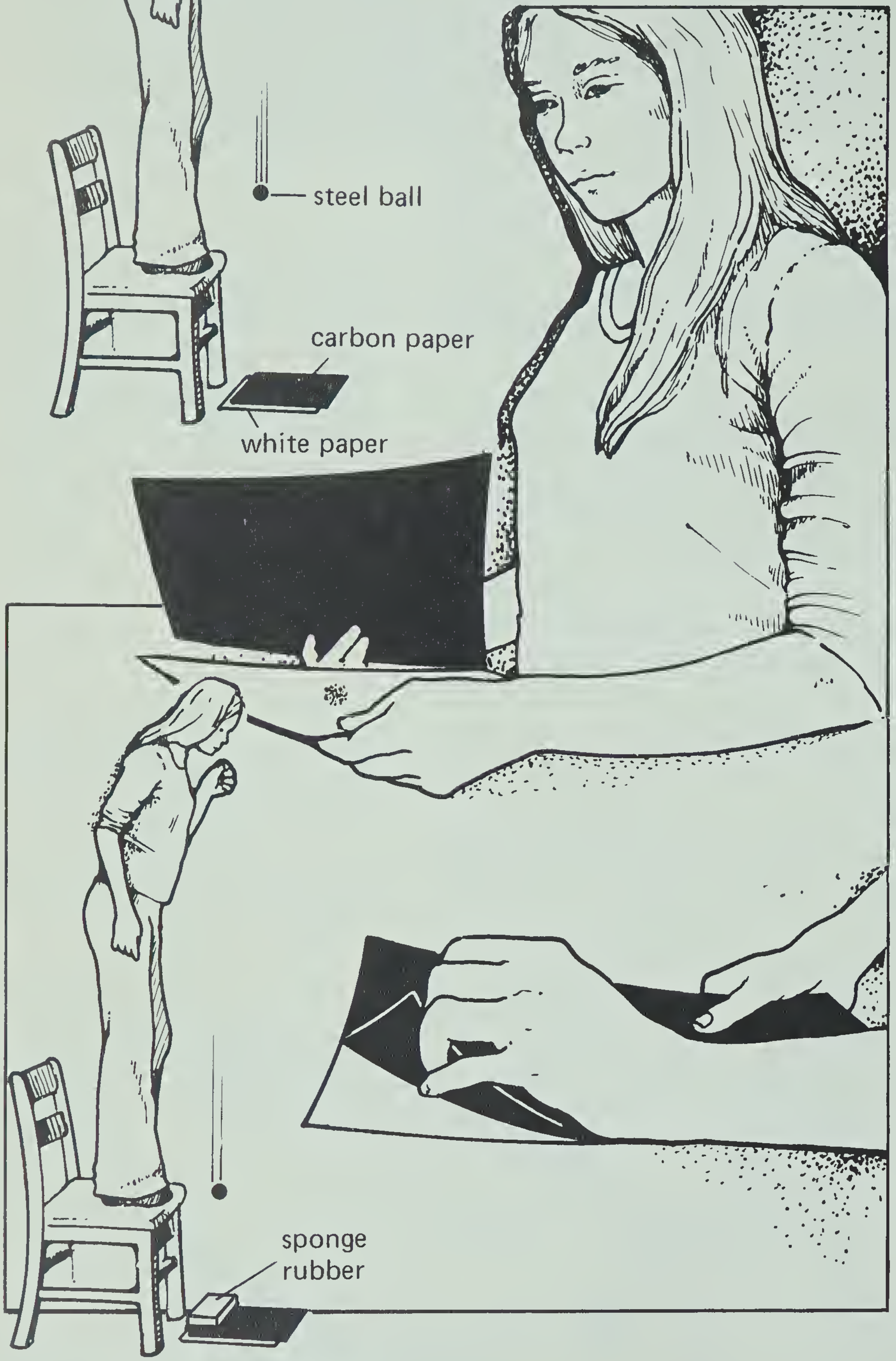
As the sponge rubber is compressed, it slows the ball down. This reduces the force.



See for yourself how a slowdown affects force. You will need five minutes and the following materials.

1 sheet white typing paper
1 sheet carbon paper
steel ball, 15 mm in diameter
piece of sponge rubber, 0.5 to 1 cm thick





A. Put the typing paper on the floor beside a chair. Cover the typing paper with the carbon paper (coated side down). Stand on the chair and "bomb" the papers from eye level as shown.

B. Remove the carbon paper and look at the impression made by the ball on the white paper. Circle the impression, using a pencil.

C. Replace the carbon paper. Put the sponge rubber on top of the carbon paper (be sure it doesn't lie over the penciled circle). Now repeat the drop, aiming for the center of the sponge rubber.

D. Remove the sponge rubber and the carbon paper. Compare the two impressions on the white paper.

10-4. The new one. The sponge rubber slowed the ball down, so the force on the carbon paper was less.

● 10-4. Which impression is lighter, the circled one or the new one? Why?

PRESSURE

"Two hands for beginners." You've probably heard that on the ball field many times. But it isn't just beginners who will do better catching with both hands. Practically anybody will. One reason, of course, is that two hands are better than one for holding onto things. But there's another reason — reduced *pressure*.

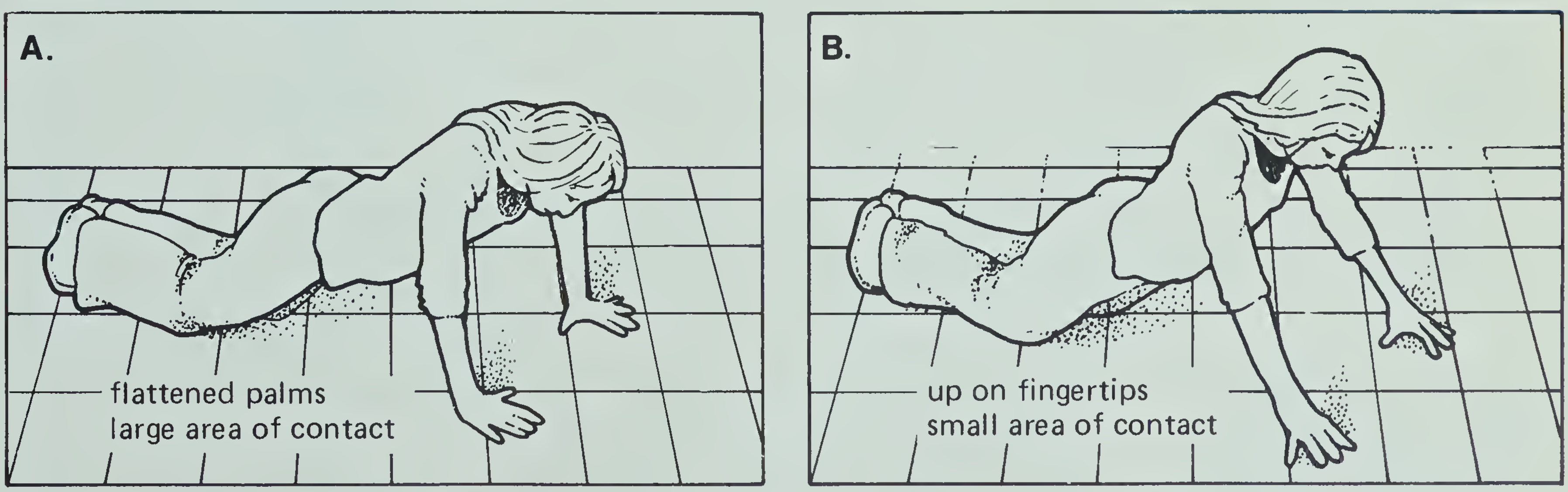
Pressure is described as the amount of force per unit of area. (If you are unfamiliar with this use of the term, consult "Resource Unit 6: Pressure.") P = F/A.

If a ball hits you on the end of a finger, it hurts. That's because all the ball's force is concentrated on one small area — your fingertip. Since the ball's force is considerable and the area of contact is tiny, the pressure is very high. It can even break your finger!

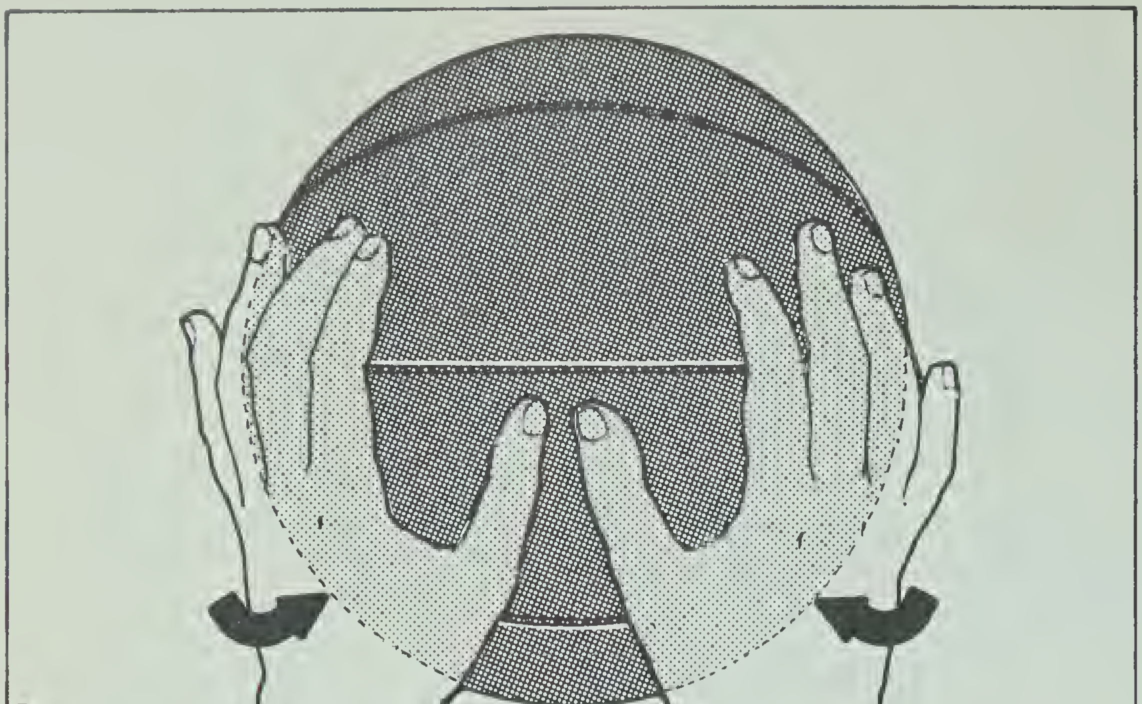
Suppose the ball had hit both your hands instead of just your fingertip. The pressure would have been less. The bigger the area over which the force is spread, the smaller the pressure.

Try feeling a little pressure. Do a push-up with your hands flat on the floor, as in A below. Then do a second one on your fingertips as in B.

10-5. The push-up on the fingertips. The force of your body is concentrated on a smaller area when you use your fingertips.



- 10-5. During which push-up did you feel more pressure? Why?



Larger surface of two hands reduces the pressure

Now what does this have to do with catching a ball? Suppose you tried to catch a softball with one bare hand. The force of the ball's impact would be concentrated on a fairly small area. The ball might bounce away.

When you use two hands, the force is spread over a larger area. This reduces the pressure of the ball against your hands. It also lessens your chances of dropping the ball. When catching a big ball, like a basketball or football, you especially need to use two hands.

10-6. It lessens.

☆ **10-6. What happens to the pressure of a ball's impact as you increase the area over which the force is applied?**

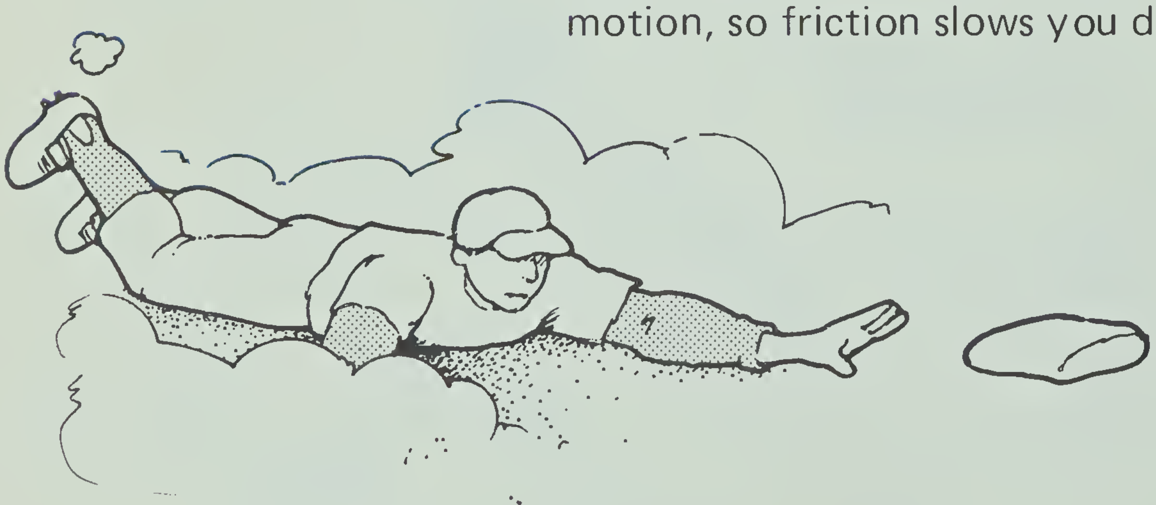
10-7. The force is spread over a larger area, so the pressure is less.

• 10-7. Why is it easier to catch a baseball using two hands instead of one?

10-8. ["The force per unit area" is best answer.]

• 10-8. What is *pressure*?

Balls are not the only things that need to be stopped in sports. Sometimes the players need to stop quickly. Pressure is important here too, but so is *friction*. Friction is a force between two solid objects that touch each other. Friction always opposes motion, so friction slows you down.



In baseball, a sliding runner uses friction. As you slide, your body contacts the ground. This creates a lot of friction, and you stop. What's more, when you dive for the base, the force of your body hitting the ground is spread over a larger area than it would be if you went in standing up.

10-9. It is reduced.

• 10-9. When a force is spread out over a larger area, what happens to the pressure at any one point?

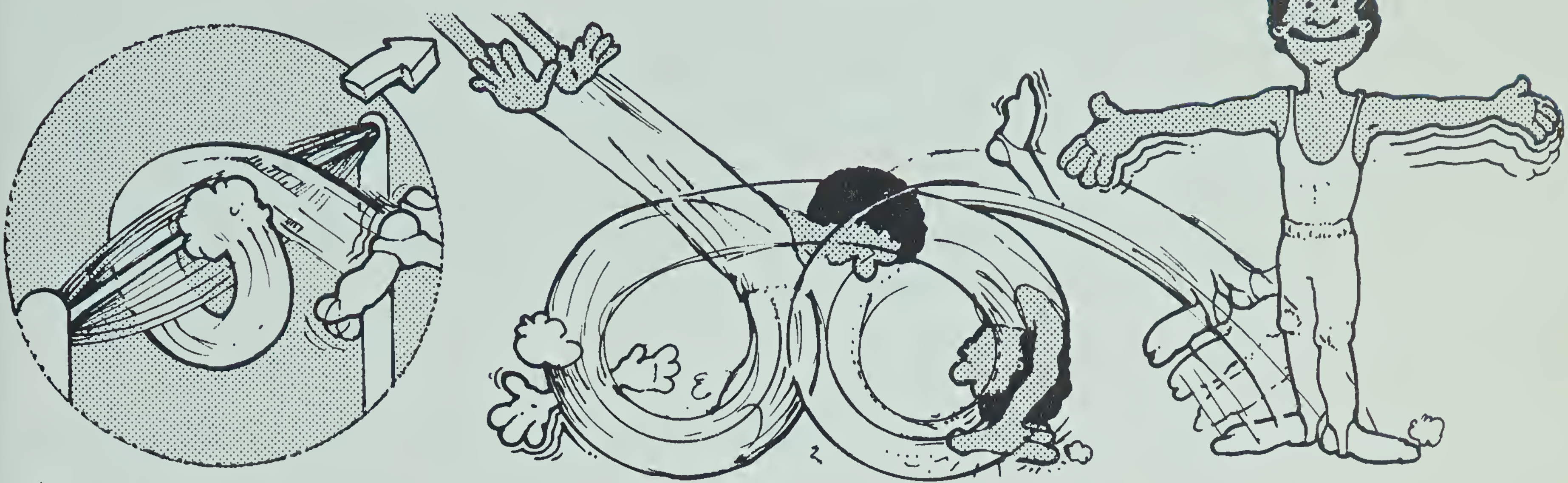
Reducing the pressure at any one point on your body decreases your chances of injury. Another good reason to slide is that you are harder to tag.

- 10-10. When you slide, what force causes you to stop?

10-10. Friction

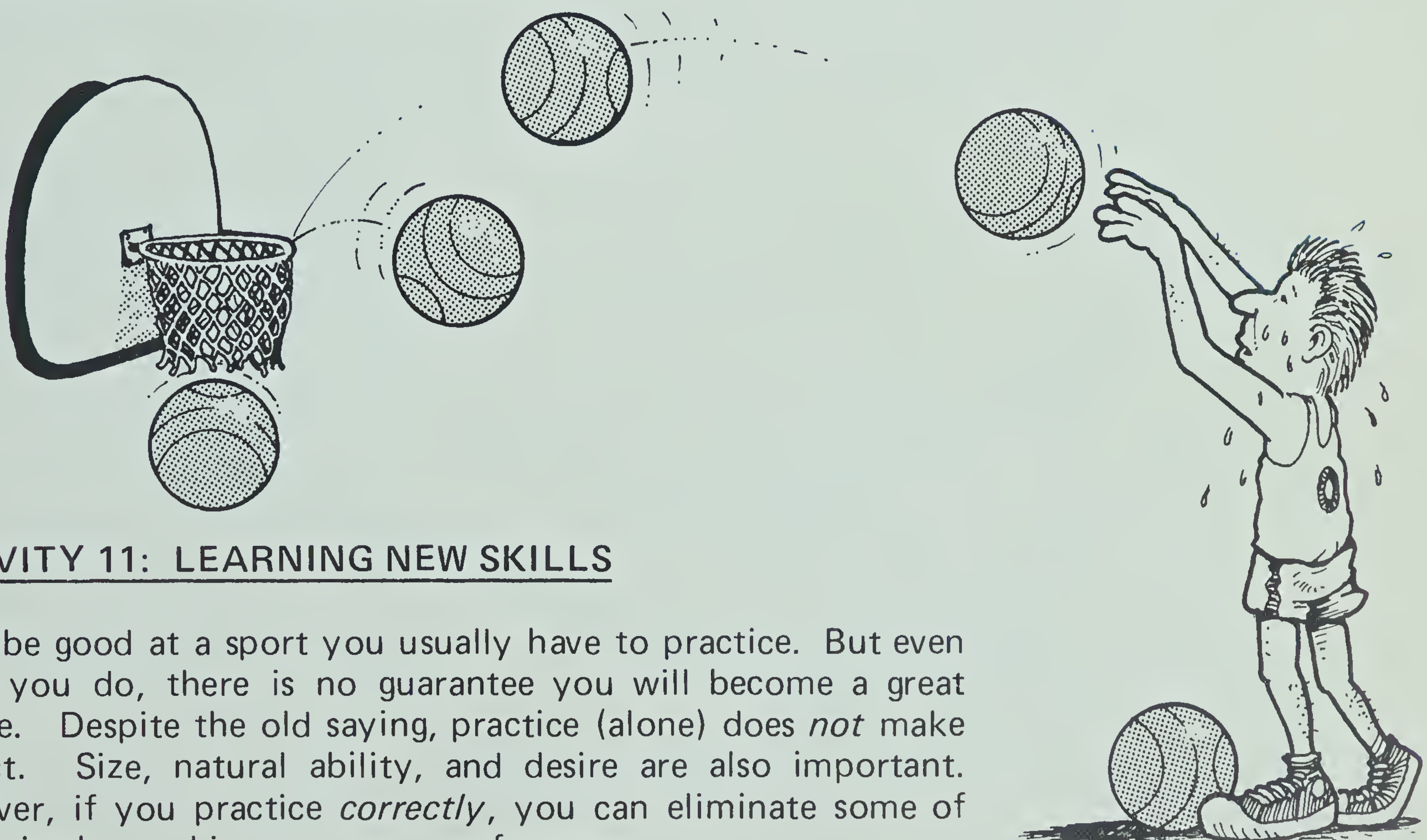
- 10-11. Tumblers and parachutists also need to hit the ground safely. You may have noticed that they often roll over once or twice before stopping. What is the advantage in doing that?

10-11. It increases the period of impact with the ground. That lowers the force of impact.



☆ **10-12. You probably know that a heavy person is harder to stop than a light one. But other than weight, what two factors are important when stopping a person or ball?**

10-12. Absorbing the force of impact and reducing its pressure



ACTIVITY 11: LEARNING NEW SKILLS

To be good at a sport you usually have to practice. But even when you do, there is no guarantee you will become a great athlete. Despite the old saying, practice (alone) does *not* make perfect. Size, natural ability, and desire are also important. However, if you practice *correctly*, you can eliminate some of your mistakes and improve your performance.

ACTIVITY EMPHASIS: Practice of any sort is important in learning new skills, but spaced practice results in more immediate improvement than massed practice.

MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter.

For correct practice, proper technique and good equipment are important. So is efficient use of your practice time. You don't have forever to learn a new skill or practice an old one. How do you take full advantage of the time available? Do you use it all at once in one long practice session? Or do you divide your practice time up into shorter periods, with rest in between?

Both practice methods are in use. The nonstop method is called *massed* practice (for example, a basketball player shooting 100 free throws without a break). The method that calls for rest periods during practice is called *spaced* practice (for example, a basketball player shooting 100 free throws in five 20-try sets, with ten minutes of rest after each set).

Which practice method, massed or spaced, is better? Although the answer is not always simple, many experts favor spaced practice for the quick learning of new motor skills. (Of course, all practice depends on repetition, so the spacing can't be too wide. Shooting one free throw a month for nine years and two months isn't practice.)

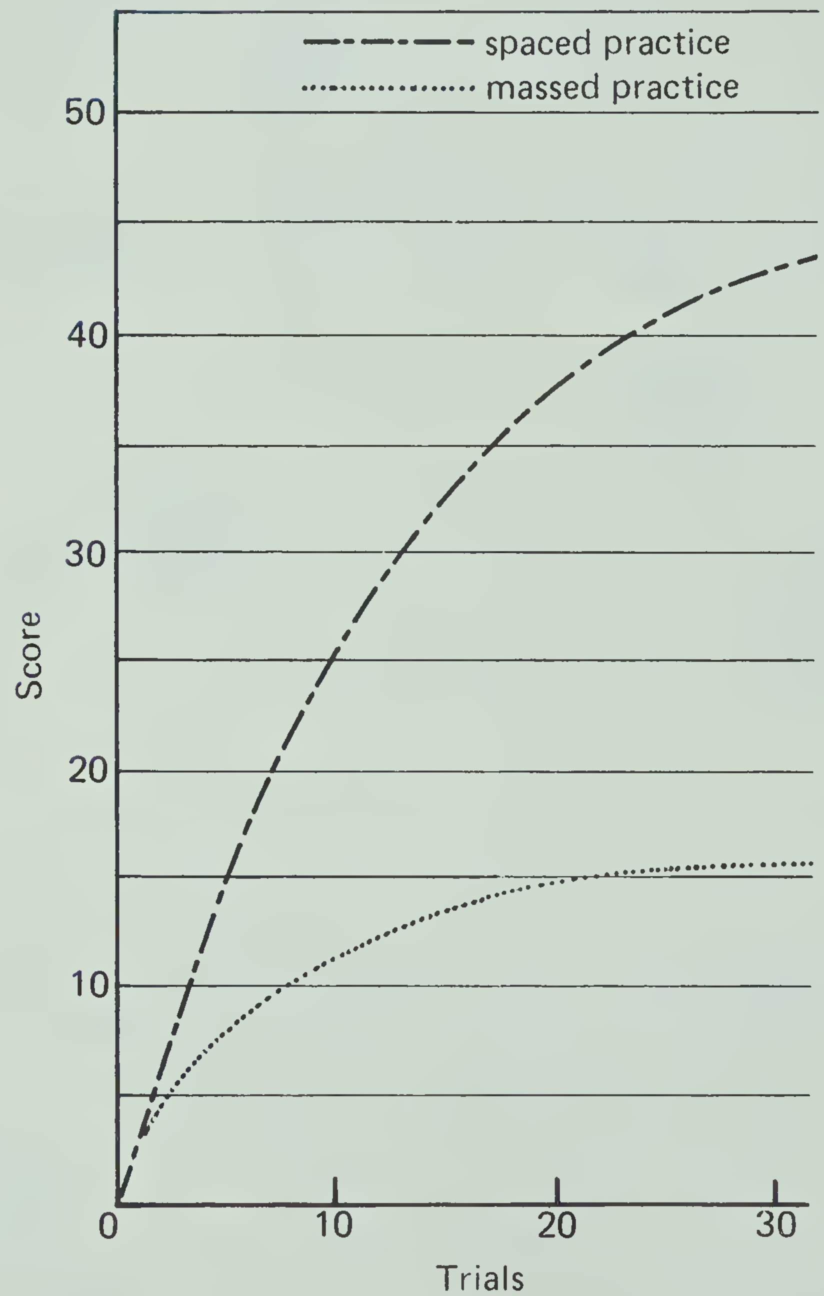


Figure 11-1

The difference between massed and spaced practice has been studied a number of times. In one typical study, two groups of students learned to perform a simple exercise in hand—eye coordination. None of the students had ever practiced this exercise before.

Every student had 30 tries lasting 10 seconds each. Students in the massed-practice group made their 30 trials without stopping. Those in the spaced-practice group rested for half a minute after each trial. The graph in Figure 11-1 shows how the two groups did. (Can you follow this graph? If not, look at "Resource Unit 2: Reading Graphs" before you continue.)

☆ **11-1. According to the graph on page 48, did both groups improve?**

11-1. They both improved.

● 11-2. After about 20 trials, what happened to the rate of improvement in the massed-practice group?

11-2. It leveled off.

● 11-3. What conclusions can you draw about massed and spaced practice from this graph?

11-3. Both will result in improvement, but spaced trials will result in more improvement.

For learning this skill, spaced practice was better than massed practice. This is true for most activities. If you take breaks during practice, you will usually do better in the end.

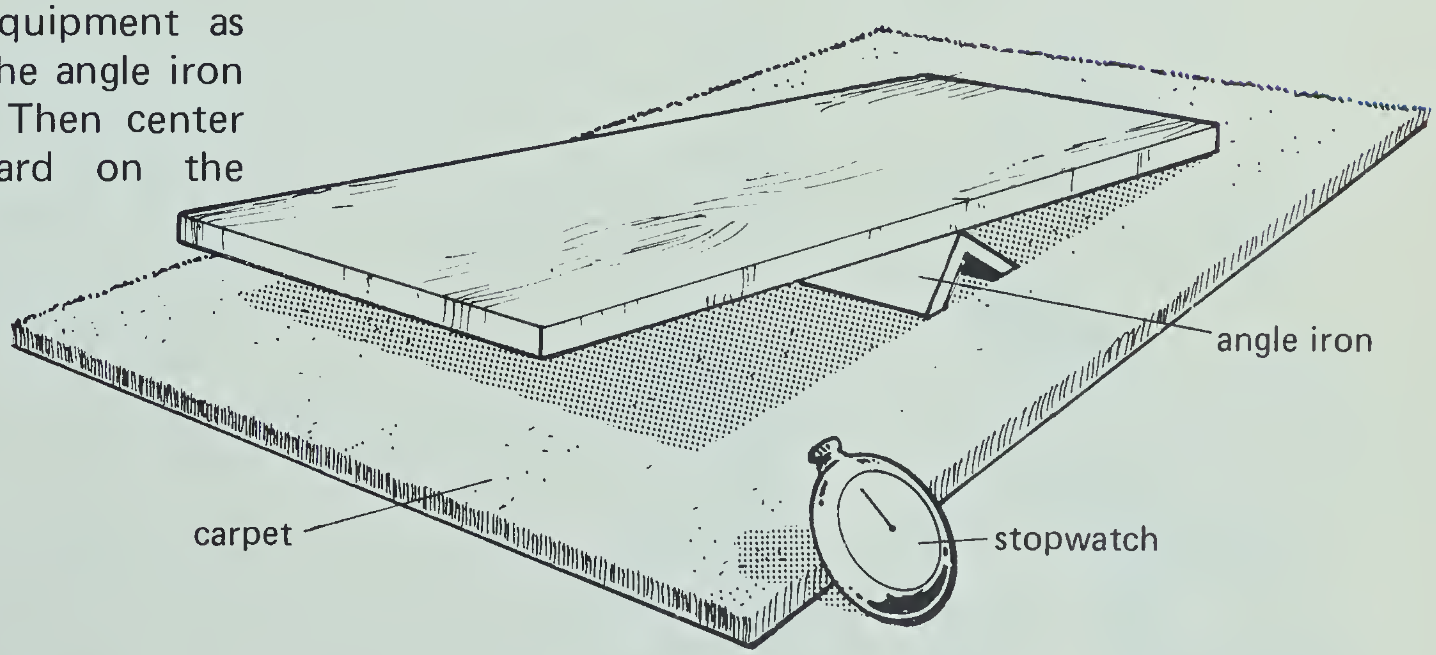
Now try this investigation. It compares the effectiveness of massed practice and spaced practice in the learning of a balancing task. You will need two time periods of at least forty minutes each, four other students, and the following materials.

Suggest to student that Steps A through D be done in one time period and the remaining steps in another.

balancing board, about 45 cm × 30 cm
5-cm angle iron, 30 cm long
square of carpet, 60 cm or larger (or heavy cardboard)
stopwatch (or watch with sweep-second hand)

Two of your classmates will do massed practice (MP), and two will do spaced practice (SP). You will need to decide who is to do which. One member of each group, MP or SP, will also be timekeeper for the other group. The timekeeper's job is to monitor the stopwatch and call out the beginning and ending of each trial. Choose your timekeepers.

A. Set up the equipment as shown. Center the angle iron on the carpet. Then center the balance board on the angle iron.



Each subject will have 15 trials on the balance board. A trial lasts 60 seconds. That much is the same for both groups. The difference is in the timing.

B. Copy the charts below in your notebook. Fill in the names of your subjects in the proper blanks.

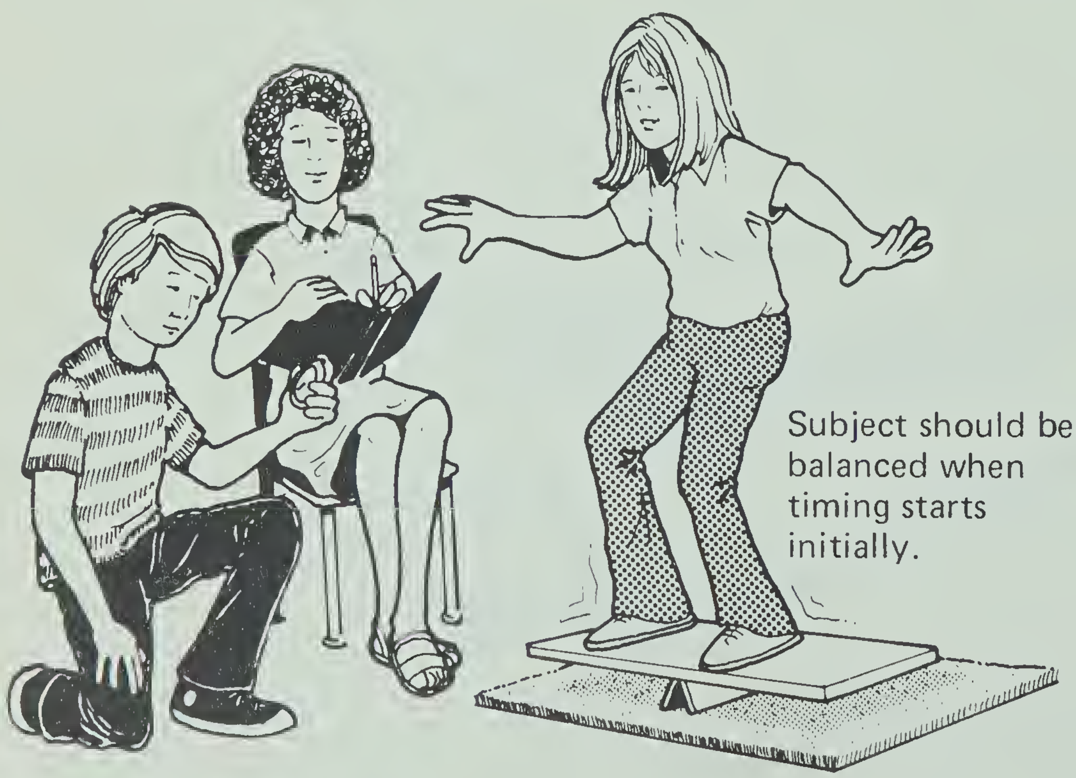
MASSED	TRIALS														
SUBJECTS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
AVERAGE															

number of times off balance, each trial

SPACED	TRIALS														
SUBJECTS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
AVERAGE															

number of times off balance, each trial

As the major investigator, you have several jobs. One of them is to count the number of times each subject loses his or her balance on the board. You need to record this number for each trial, as soon as the timekeeper tells you that 60 seconds are up. (A loss of balance has occurred whenever either end of the balance board touches the carpet during a trial.)

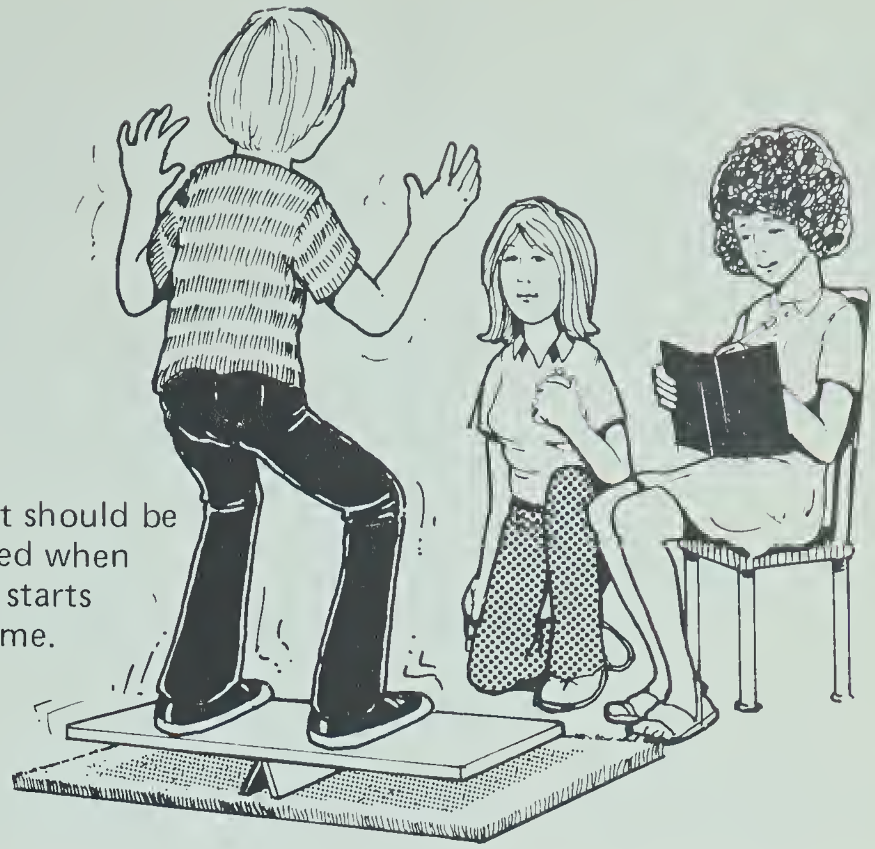


C. When you and the timekeeper are ready, have one of your MP subjects get on the board and try to balance as shown. Count the number of times the board is allowed to touch the carpet.

When 60 seconds have passed, the timekeeper should say "Time." That is a signal for you to record the number of misses and to start a new count. It is not a signal to the subject, who should keep on trying to balance. Continue this procedure until 15 trials have been completed.

D. Repeat Step C with the other MP subject.

E. Now it's time to switch. A member of the MP group should take over as timekeeper, and the SP members should take their turns on the board. The trial procedure is the same EXCEPT that after each 60-second trial (called by the timekeeper) the subject on the balance board should step off the board to rest for 20 seconds (timed by the timekeeper). Continue until 15 trials have been completed.



Subject should be balanced when timing starts each time.

F. Repeat the 15 trials, with rests, for the second SP subject.

G. Fill in the last row of blanks in your tables by averaging the times off balance for each group during each trial. (If you have trouble with the figures, look at "Resource Unit 1: Averaging.") Then, using these averages, construct a graph with axes like those shown here. (Is graphing a problem for you? If so, look at "Resource Unit 4: Making Graphs.") Complete and label the average SP and MP lines.

• 11-4. In your investigation, what was the overall trend for each type of practice?

11-4. [Answers will vary, but both practices should show improvement, indicated by a decrease in the number of times off balance. The spaced practice should show the greater improvement.]

• 11-5. Are your data in this investigation consistent with the trends others have found when comparing spaced and massed practice?

11-5. Yes [Answer may be "no" if data show it.]

☆ **11-6. In general, how does massed practice compare with spaced practice in the learning of new skills?**

11-6. Spaced practice gives more improvement than massed practice.

ACTIVITY EMPHASIS: Student performance scores on various motor ability tests tend to have a normal distribution.

MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter.

ACTIVITY 12: NOT EVERYONE'S THE SAME

Beth Todd has just completed four motor (sports) ability tests at her school. Take a look at the results.

MOTOR ABILITY TEST

Name: Beth Todd Age: 16 Sex: Female

Speed (50-m run)	Response Time (ruler drop)	Agility (shuttle run)	Leg Power (vertical jump)
8.0 sec	0.16 sec	14.3 sec	70 cm

By themselves, Beth's scores on the motor ability tests don't tell you much. What you really need to know is how she compares with other students. To learn this, you would have to see how other students did on the tests. Figure 12-1 below shows you a graph of how a large number of teenagers performed in the 50-metre run.

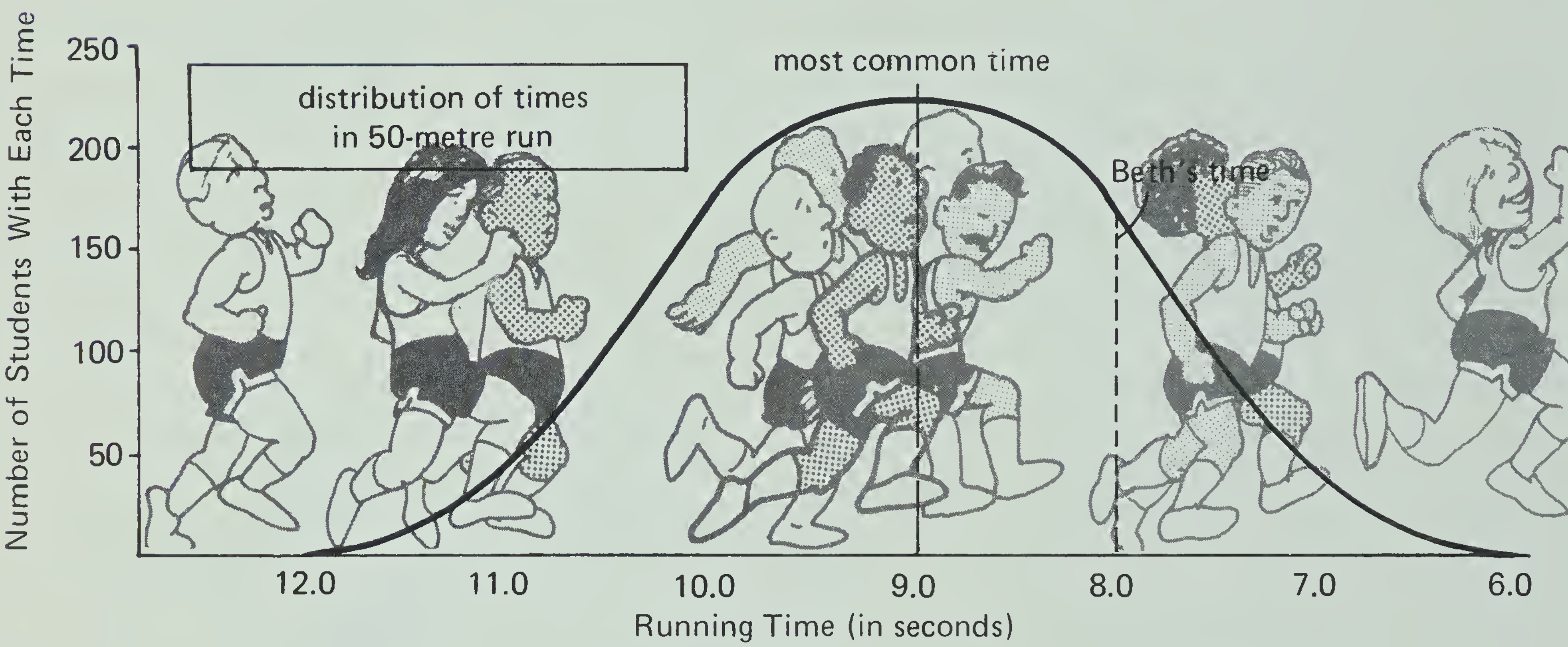


Figure 12-1

If you have trouble understanding what this graph shows, take a look at "Resource Unit 2: Reading Graphs."

From Figure 12-1 above, you can see that the speed of individuals varies widely. Notice that the most common running time (9 seconds) is in the middle of the curve. The very fast runs and very slow runs are the least common. They are at the ends of the curve.

A similar variation is found in the scores on the other tests Beth took. If you were to graph the response times or agility scores of a large number of people, those curves would also have bell-shaped humps in the middle. Features that vary in this way are said to be "normally distributed." Their graphs are called *normal curves*.

- 12-1. What is the shape of a normal curve?

12-1. Like a bell, but broader near the base

- 12-2. What part of the normal curve contains the largest number of scores?

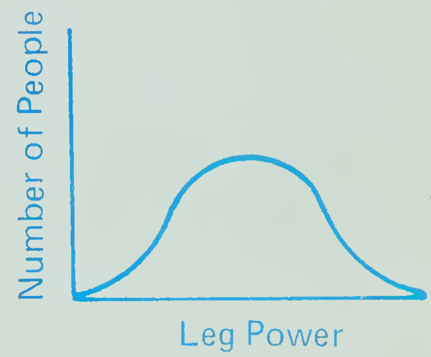
12-2. The middle

☆ **12-3. Suppose you graphed a large number of scores for a feature like leg power. How would you expect the scores to be distributed?**

12-3. Normally

- 12-4. Copy Figure 12-2 below in your notebook. Then draw the curve showing the distribution predicted in Question 12-3 above.

12-4. The curve should be bell-shaped but need not begin at the vertical axis, as shown here.



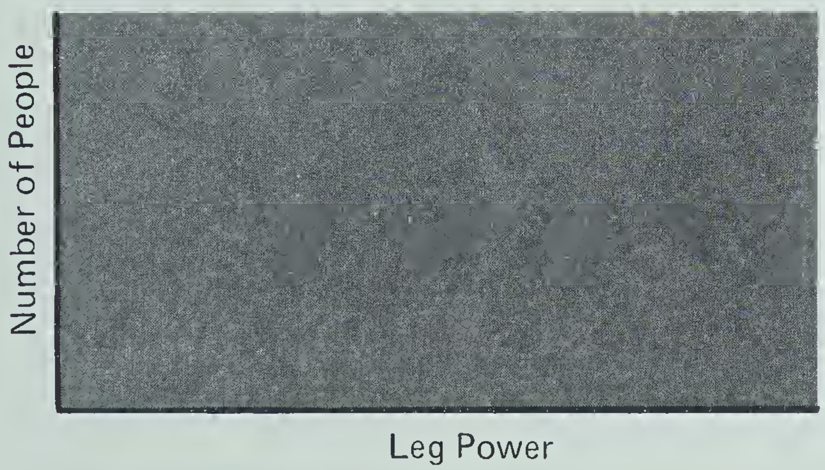


Figure 12-2

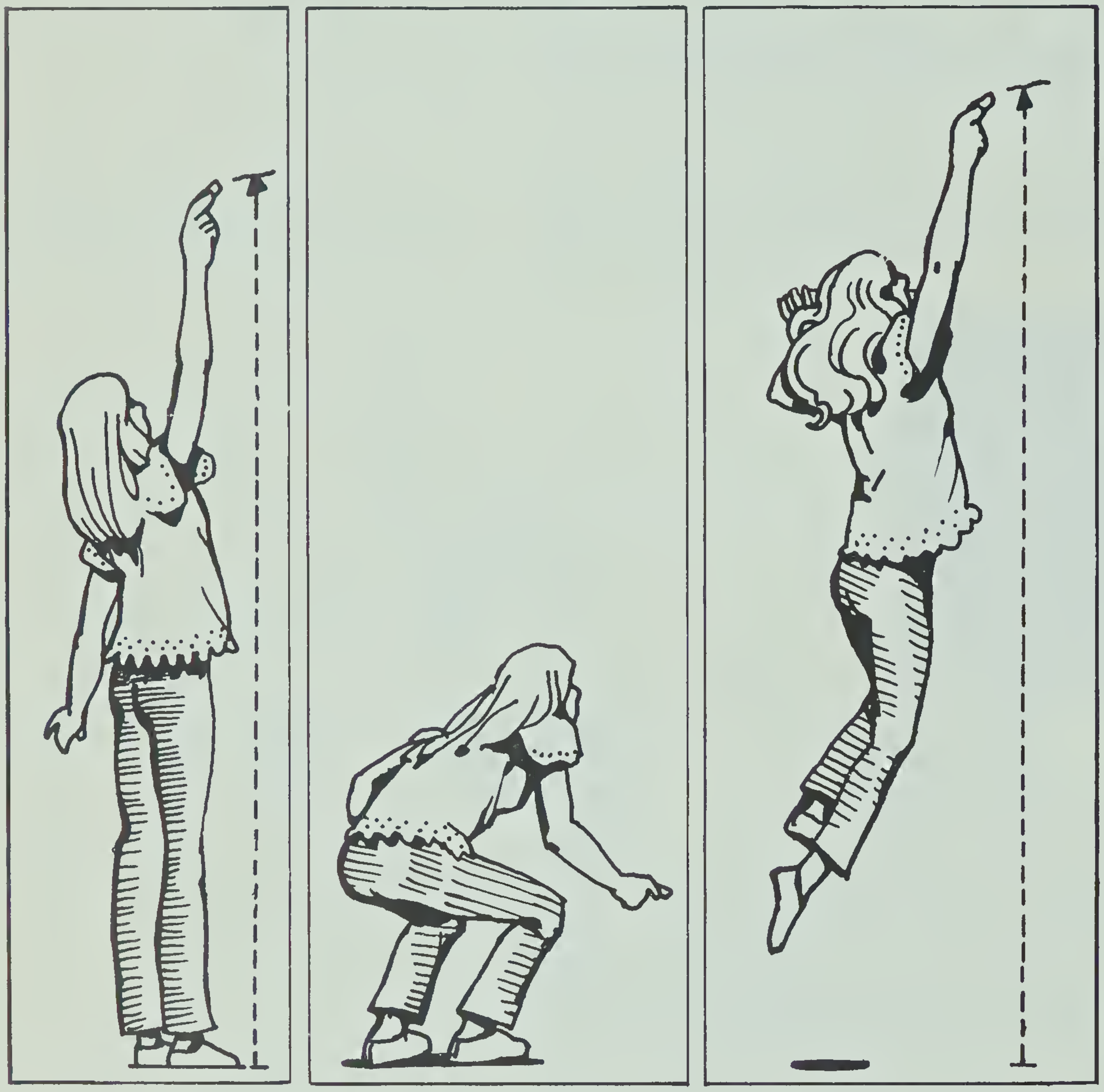
If you don't feel good about your understanding of "normal distribution," look at "Resource Unit 19: Normal Curve."

Now try an investigation to find out how a few of your classmates vary in leg power. You will be measuring their vertical jumping ability. You will need ten subjects, at least fifteen minutes, and the following materials.

metre stick
chalk
eraser

If you need help in measuring distances in metric, look at "Resource Unit 9: Measuring Length" before you proceed with the investigation. Likewise, if you are unsure how to average, look at "Resource Unit 1: Averaging" before going on.

SUBJECT	TRIAL 1	TRIAL 2	AVERAGE
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			



ITEM	SCORE	NUMBER OF SUBJECTS
Lowest score		
Lowest score plus 1 increment		
Lowest score plus 2 increments		
Lowest score plus 3 increments		
Lowest score plus 4 increments (same as highest score)		

A. In your notebook, make a table like the one shown at left. Be sure to leave enough space for writing data.

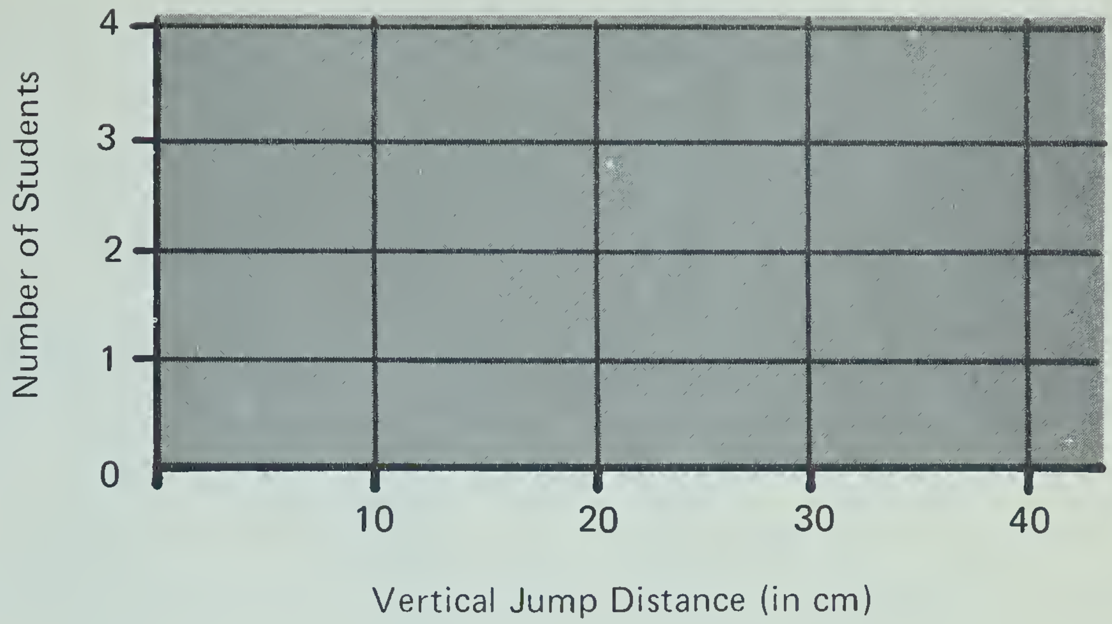
B. Have one of your subjects stand sideways beside a wall, holding the chalk in his or her dominant hand. Have the subject reach as high as possible (with heels on the floor) to make a chalk mark on the wall.

C. Have the subject first crouch and then spring straight up as high as possible, making a second mark at the highest point. Measure the vertical distance (in centimetres) between the two marks. Record the figure in the table in your notebook.

D. Erase the upper mark (stand on a chair, if necessary), and then have your subject jump again, making a new high mark. Measure the new vertical distance, averaging it with the first one to get subject's score.

E. Repeat Steps B, C, and D for each of your remaining nine subjects. Determine the lowest and highest average scores from your table. Subtract to get the difference. Divide this number (the difference) by four. The result is your height increment. Make a new table like that shown. Enter the five scores and the total number of subjects that belong in each group. (Scores won't be exact; place each subject in the box that best represents subject's score.)

F. Now you are ready to convert the data from your last table to a graph. Draw in your notebook a set of graph axes like those shown here. The numbers along the horizontal axis should include the range (cm) of vertical distances your subjects jumped. Then enter your data on the grid and connect the points to form the graphs resulting line. ("Resource Unit 4: Making Graphs" can provide help if you need it.)



Does your graph look something like your answer to Question 12-4 on page 53? Don't worry if the curve appears a bit jagged. It usually takes lots of scores to produce a smooth normal curve. Your number of subjects may be too small to give you a perfect curve.

• 12-5. Describe the way leg power seems to vary among the students in your class.

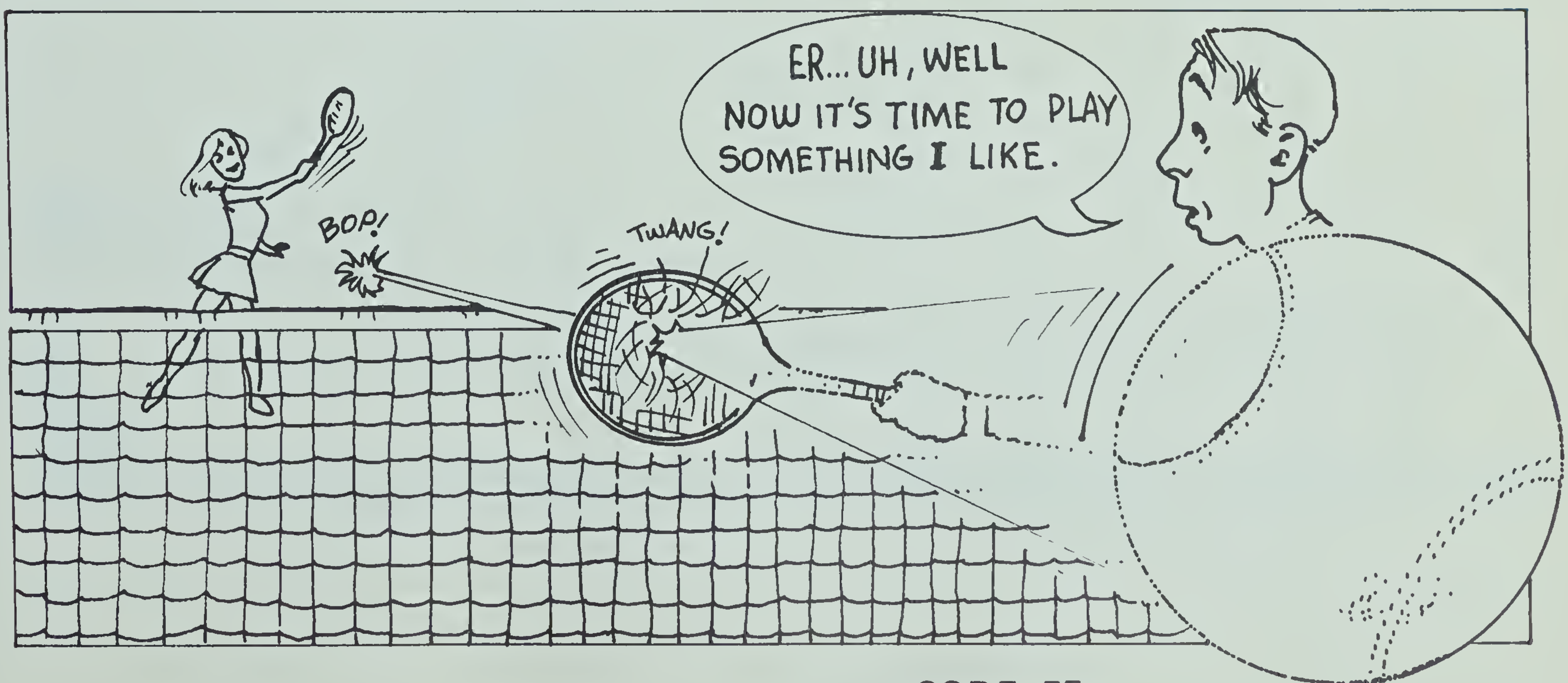
• 12-6. What do you think the distribution would have looked like if you had used a larger number of subjects?

12-5. [Answers will vary. With only ten subjects, almost any result is possible. The usual response is that it bunches toward the middle.]

12-6. A normal curve

Very few things are not normally distributed. There will always be superior and inferior performers in every sport. You will probably find that you are good at some things and not so good at others. Don't worry, that's normal.

You may wish to suggest combining the results from several students' data to better show the distribution suggested in Question 12-6.



Advanced

ACTIVITY 13: PLANNING

Activity 14 **Page 57**

Objective 14-1: **Identify maximum or minimum points from graphs representing the height, range, speed, and time relationships of projectiles.**

Sample Question: Figure 13-1 below shows how the height of a long jumper changed with time from "lift off." What is the jumper's maximum height, and at what time was it reached?

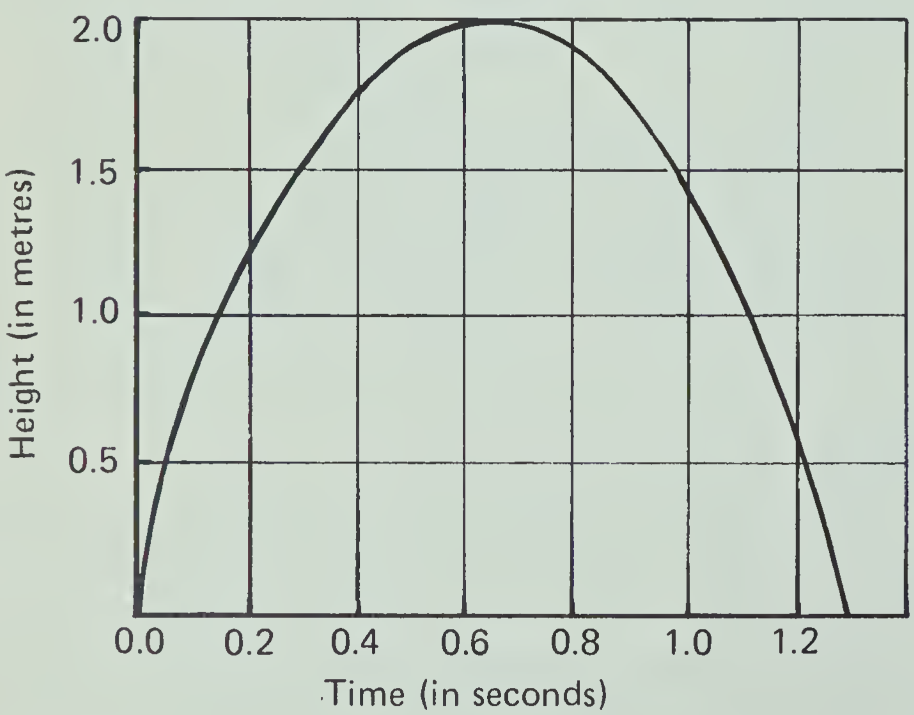


Figure 13-1

Activity 15 **Page 64**

Objective 15-1: **Tell what kinetic energy is and what happens to it in both inelastic and elastic collisions.**

Sample Question: During most inelastic collisions,

A. kinetic energy is increased.
B. some kinetic energy is changed to heat.
C. kinetic energy remains the same.
D. some kinetic energy is created.

Objective 15-2: **Tell what happens to the energy involved in collisions.**

Sample Question: A tennis ball with a kinetic energy of 20 joules hits the surface of the court. It rebounds with a kinetic energy of 18 joules. What happened to the two missing joules of energy?

Activity 16 **Page 69**

Objective 16-1: **Tell what *momentum* is and calculate it before or after a collision.**

Sample Question: A moving 0.90-kg bat has a momentum of 13.5 kg m/s. At what speed is it being swung?

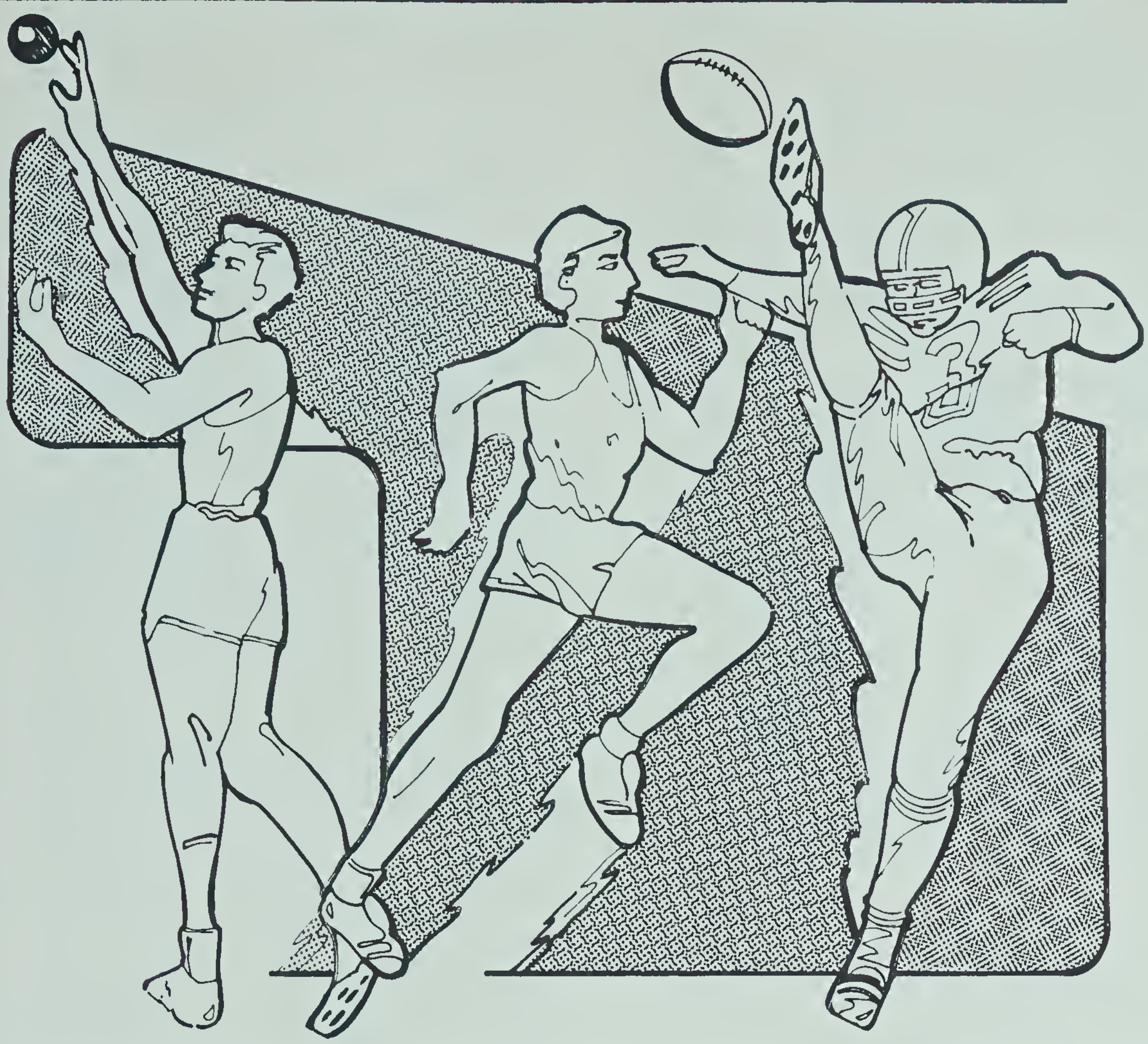
A. 12.2 m/s
B. 15.0 m/s
C. 12.6 m/s
D. 0.06 kg/s

Answers: **14-1.** 2 m and about 0.63 s; **15-1.** B; **15-2.** They were changed to heat; **16-1.** B

ACTIVITY 14: GETTING THE GREATEST DISTANCE

ACTIVITY EMPHASIS: All the following can be related graphically: the range of a projectile, its angle of projection, its time of flight, and the horizontal and vertical components of its speed.

MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter.



The athletes pictured here are all trying to project some object. Each wants to get maximum horizontal carrying distance (called *range*). To get it, each must select the best *angle of projection*. Figure 14-1 below shows what is meant by these two terms, and several others, as they relate to a punt in football.

The wind factor, sometimes important, is ignored throughout this activity.

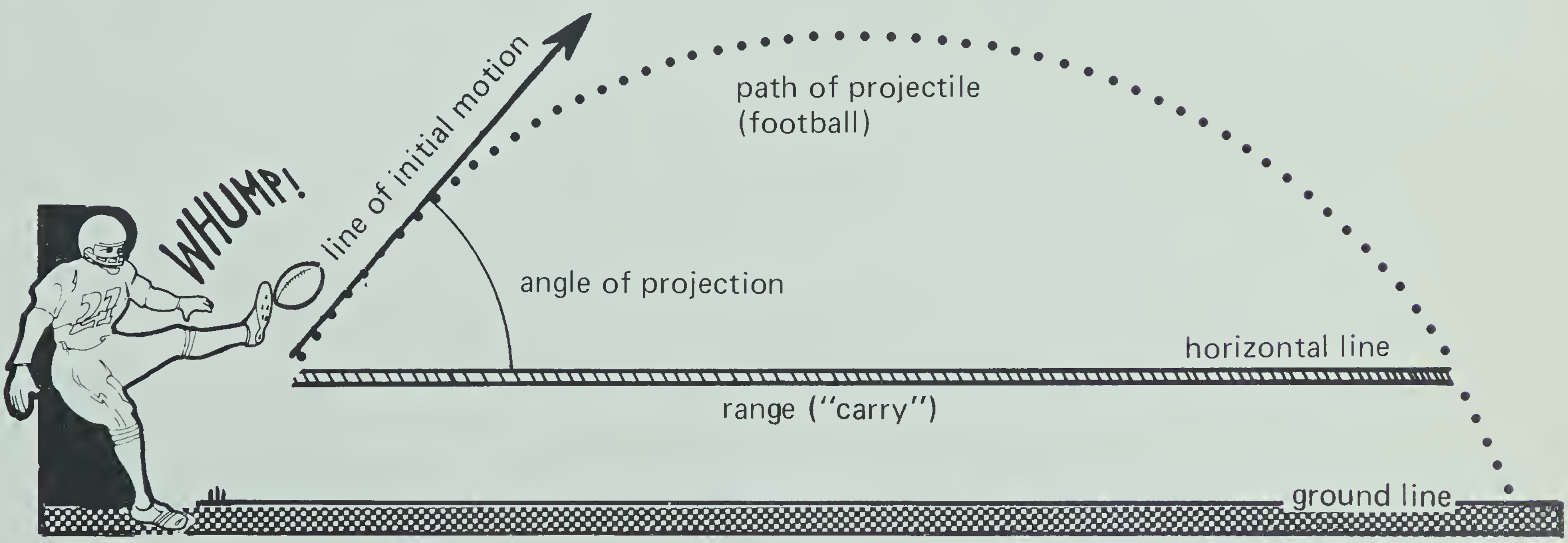


Figure 14-1

14-1. 45°

● 14-1. What angle of projection will give the greatest range?

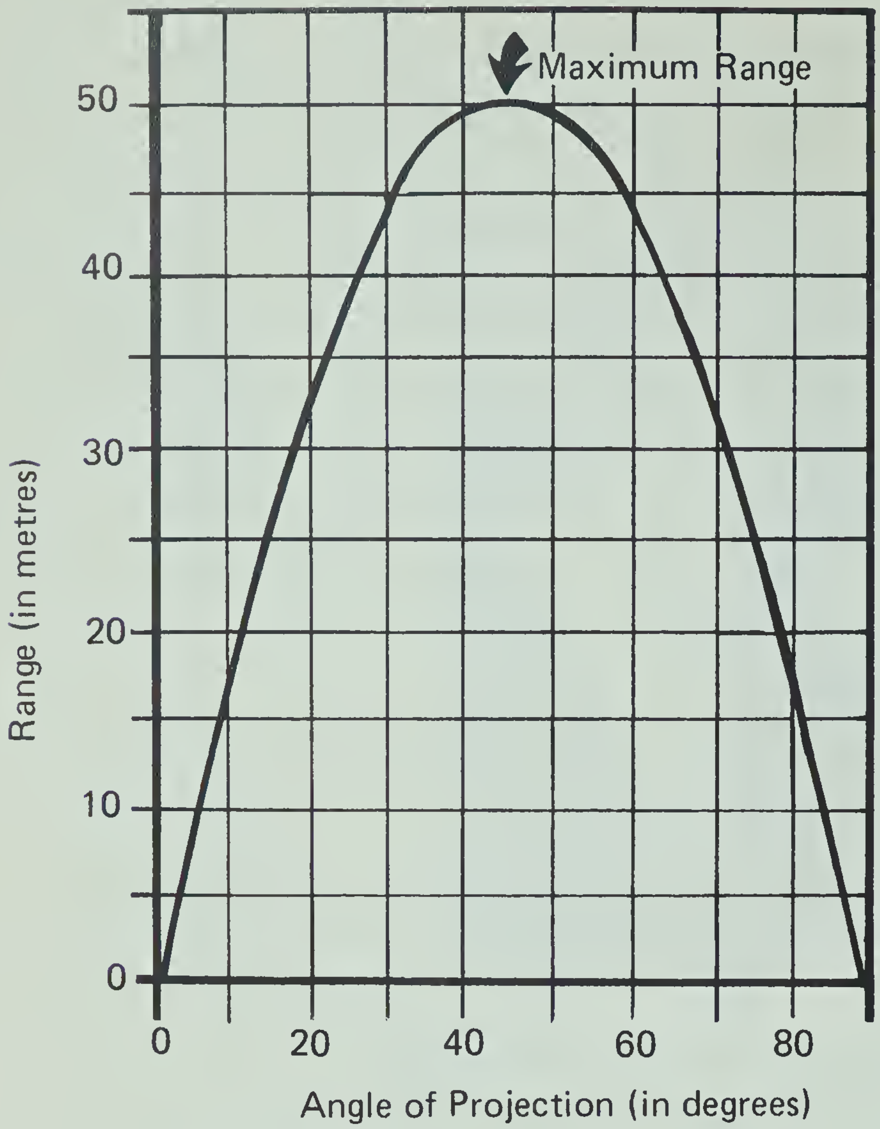


Figure 14-2

If you don't know the answer to Question 14-1 above, review core Activity 4 before continuing.

All other things being equal, a projectile's angle of projection exactly determines its range. How convenient it is, then, that all sorts of projectiles (football, shot, long jumper, and many others) get maximum range from the same angle of projection.

Figure 14-2 at left shows how the range of a projectile is affected by changes in the angle of projection. For each angle the speed of launch is the same.

(If you need help reading Figure 14-2, see "Resource Unit 2: Reading Graphs." Then continue with this activity.)

14-2. About 47 m

● 14-2. At an angle of 35°, the range is how many metres?

14-3. It increases.

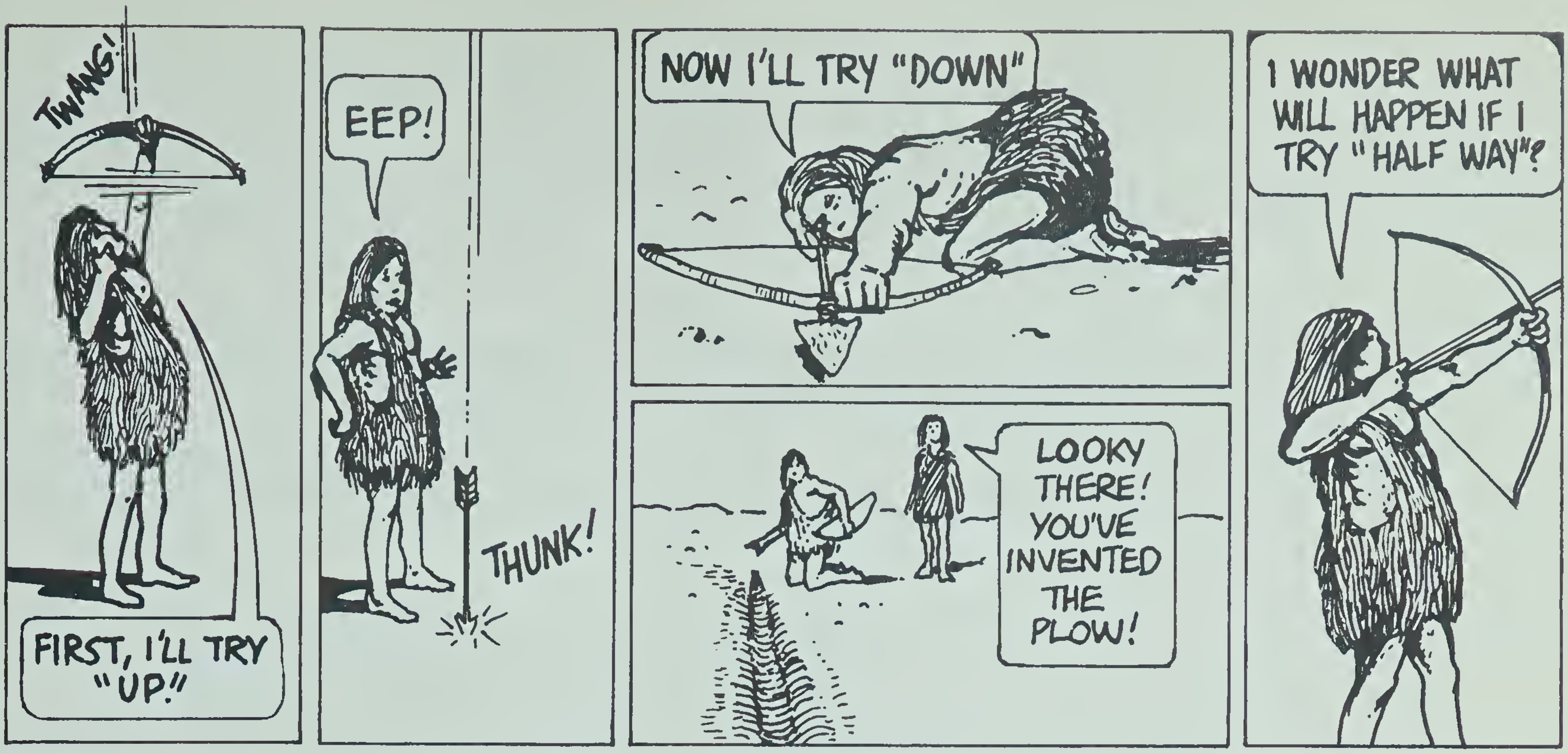
● 14-3. Does the range increase or decrease as the angle of projection increases from 35° to 45°?

14-4. It decreases.

● 14-4. Does the range increase or decrease as the angle of projection increases from 45° to 55°?

How is it possible for the range to first increase and then decrease while the angle of projection continues to increase? In other words, what accounts for the shape of Figure 14-2?

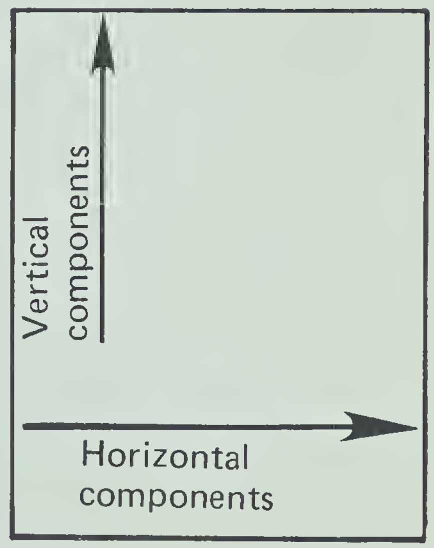
Well, to begin with, think of the extreme cases – the ones represented by the two ends of the curve. A ball or other object projected at the minimum angle of 0° would literally never get off the ground. It would have no range at all (no "carry"). And a projectile that was launched at the maximum angle of 90° would go straight up and come straight down. Again, there would be no range.



So all the positive values for range are somewhere between these two extremes. They involve angles of projection that are greater than 0° and less than 90°. That is precisely the situation shown by Figure 14-2 on page 58.

OK, you may say, but what's so special about 45°? Why is the angle for maximum range exactly 45°? Why not 46° or 44° or 40° or something else? And why is the best angle always the same? The answers to these questions will emerge in the next few pages.

For openers, think of the projectile's motion as having two parts. One part is the motion up and down (vertical components.) The other is the motion across (horizontal components.) These two sets of components can be treated as the axes of a graph.



For any given angle of projection, the path of a projectile can be represented as a line on the graph. The graph then relates the projectile's height (vertical component), at any point along its path, to its horizontal distance from its point of release. Figure 14-3 below is such a graph.

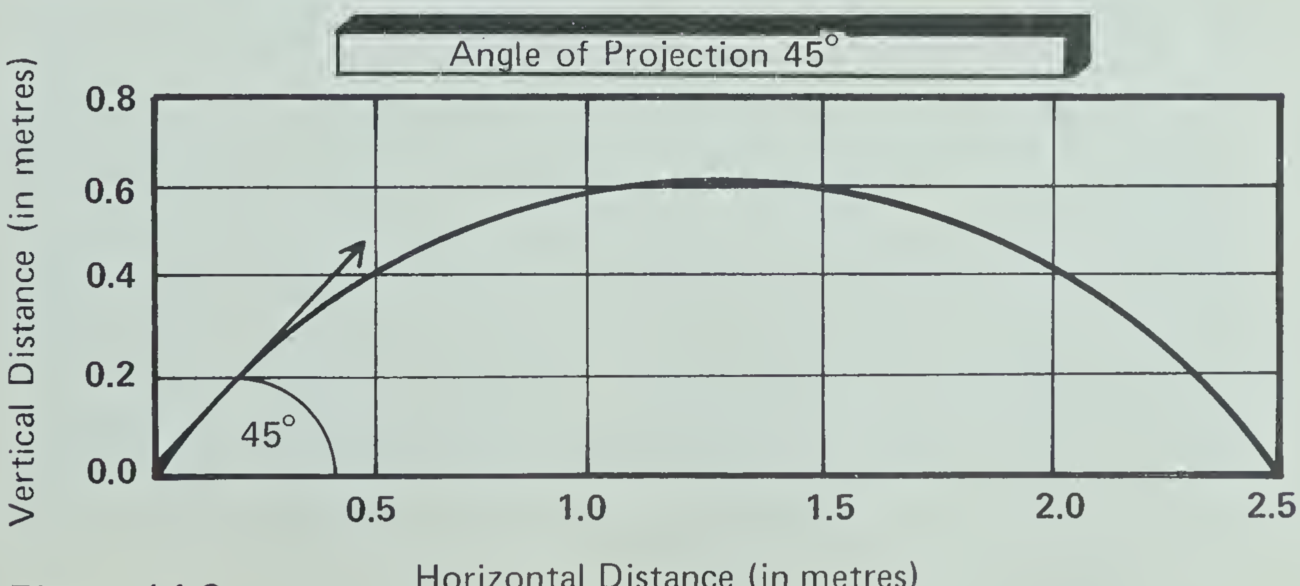


Figure 14-3

The projectile in this case was a small steel ball. It was projected by a catapult in a controlled laboratory setting where exact measurements could be made. (That accounts for the short distances.) But the same relationship between vertical and horizontal components holds true for sports projectiles like baseballs and javelins.

14-5. 0.63 m [An answer of "just above 0.6 m" is satisfactory.]

☆ **14-5. What was the maximum vertical distance (height) achieved by the projectile in Figure 14-3 on page 59?**

14-6. 1.25 m

● 14-6. How far had the projectile traveled horizontally when it reached this height?

14-7. 2.50 m

● 14-7. What was the full range of the projectile?

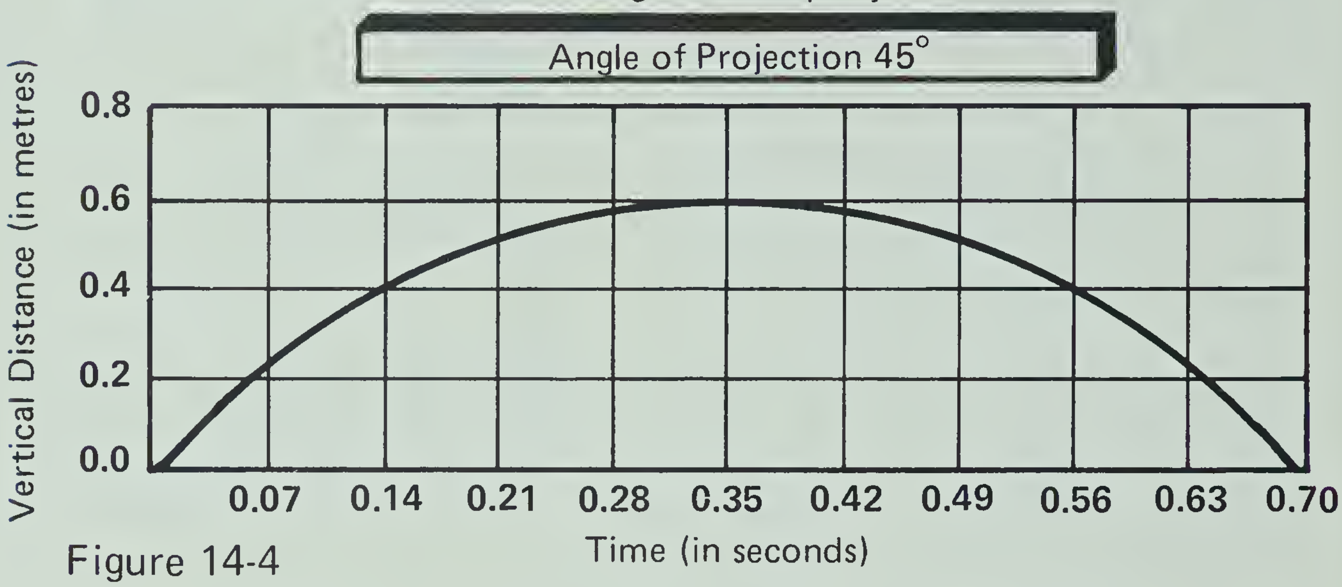


Figure 14-4

Compare Figure 14-3 (page 59) and Figure 14-4 (above). They are graphs of exactly the same motion. They have the same shape, the same angle of projection (45°), and the same vertical scale.

14-8. The horizontal scale is "Distance" for Figure 14-3 and "Time" for Figure 14-4.

● 14-8. How are the two graphs different?

☆ **14-9. In Figure 14-4 above, at what time was the projectile at its vertical maximum?**

14-9. 0.35 s

● 14-10. How long did the projectile stay in the air?

14-10. 0.70 s

The horizontal speeds of steel balls, baseballs, and other dense projectiles do not change much at all. What change there is results from air resistance. We'll say it is small enough for us to ignore. If horizontal speed does not change, then the horizontal distance traveled depends on how long the projectile is in the air. Compare the horizontal scales of Figures 14-3 (page 59) and 14-4 (above). Notice that for a horizontal distance of 0.5 m the time in motion was 0.14 s. For twice that distance, twice the time was required. Look at Figure 14-5 on page 61.

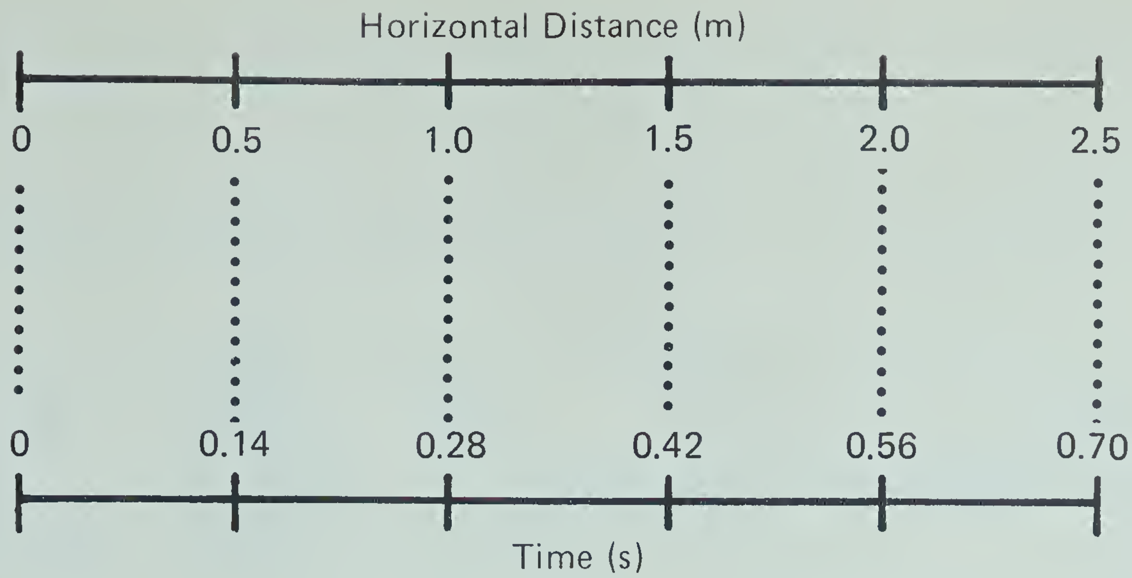


Figure 14-5

● 14-11. Suppose a baseball travels a horizontal distance of 15 m in 0.75 seconds. How long will the baseball take to travel 60 m?

14-11. 3 seconds

All this would lead you to believe that the more time in the air you give it, the farther a projectile will go. It seems obvious. But the crucial question is whether, in order to get more flight time for the projectile, you are sacrificing horizontal speed.

Remember the archers on page 59? The one who shot his arrow straight up certainly got maximum flight time. But he got no horizontal distance (so there was no horizontal speed). His arrow's range was zero. The second archer's arrow had practically zero range also. It started out fast, but it had almost no flight time since it soon crashed into the ground.

Obviously there's more to getting maximum range than just keeping the projectile in the air the longest or just projecting it horizontally at maximum speed. That's where the right combination of vertical and horizontal components comes in. Getting maximum range amounts to getting the best balance of flight time and horizontal speed.

Physicists turn this problem of finding the best balance of flight time and horizontal speed into a problem in mathematics. Although different physicists have set up different mathematics problems, the solutions are all the same. When the angle of projection is 45°, the speed with which the projectile gains altitude is equal to its horizontal speed (both about 70% of initial speed). Thus at 45° the range will be greater than for any other angle of projection.

Some sports objects may have air resistance effects that can't be ignored. For these objects, maximum range may not occur at 45°. But until experience dictates a better angle, 45° is a good one to use.

Of course, there will be times in sports when you'll want to project an object at some other angle (Figure 14-6 below).

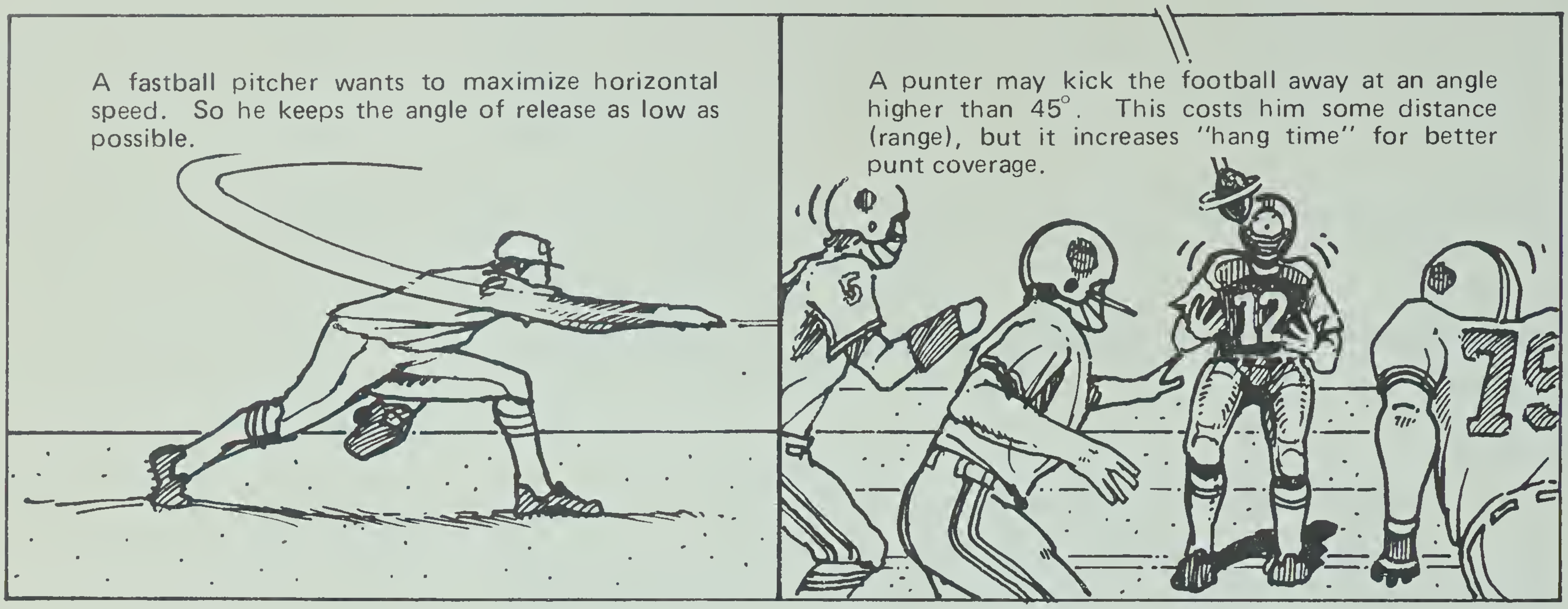


Figure 14-6

Speed is distance traveled per unit of time. The horizontal speed in Figures 14-3 and 14-4 was constant because the distance the projectile traveled (0.5 m) in each time unit (0.14 s) was the same. But the vertical distance traveled in each time unit was different, so the vertical speed must have changed continually.

14-12. The way the projectile's height changes different amounts over identical time segments

The rate at which a projectile gains (or loses) altitude is called its *vertical speed*. During a projectile's flight, horizontal speed doesn't change (see Figure 14-5 on page 61). But vertical speed changes continually. This is true for any angle of projection, not just 45°.

• 14-12. Look again at Figure 14-4 on page 60. What feature of the projectile's path indicates that vertical speed changes?

Look at Figure 14-7 below. It shows how the vertical speed of a projectile changes with time.

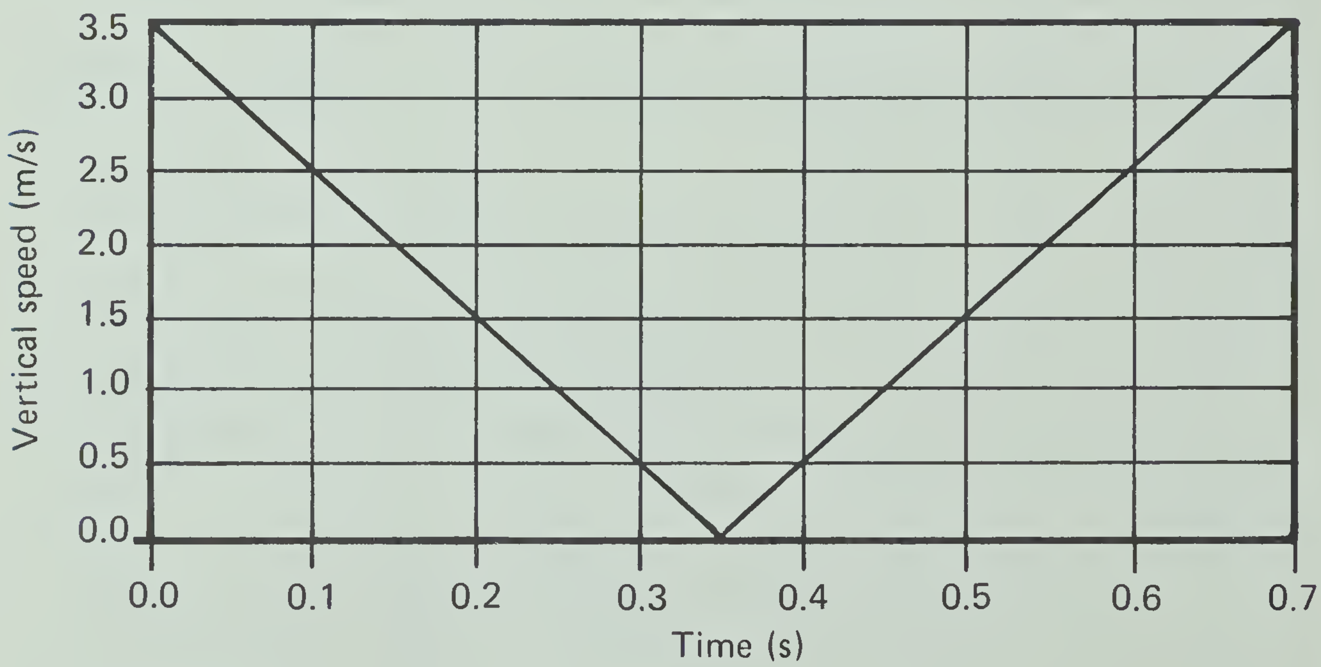


Figure 14-7

• 14-13. According to Figure 14-7 on page 62, at what two times is the projectile's vertical speed the greatest?

14-13. At 0.0 s and at 0.7 s

☆ **14-14. According to Figure 14-7 on page 62, at what time is the projectile's vertical speed at a minimum?**

14-14. At 0.35 s

• 14-15. Using your answer to Question 14-14 above, explain why the answer to Question 14-9 (page 60) is 0.35 s.

14-15. At 0.35 s the vertical speed is zero. The projectile is at the top of its rise.

☆ **14-16. To find a maximum or minimum point on a line graph, what do you look for?**

14-16. The highest or lowest value of the dependent variable on the graph

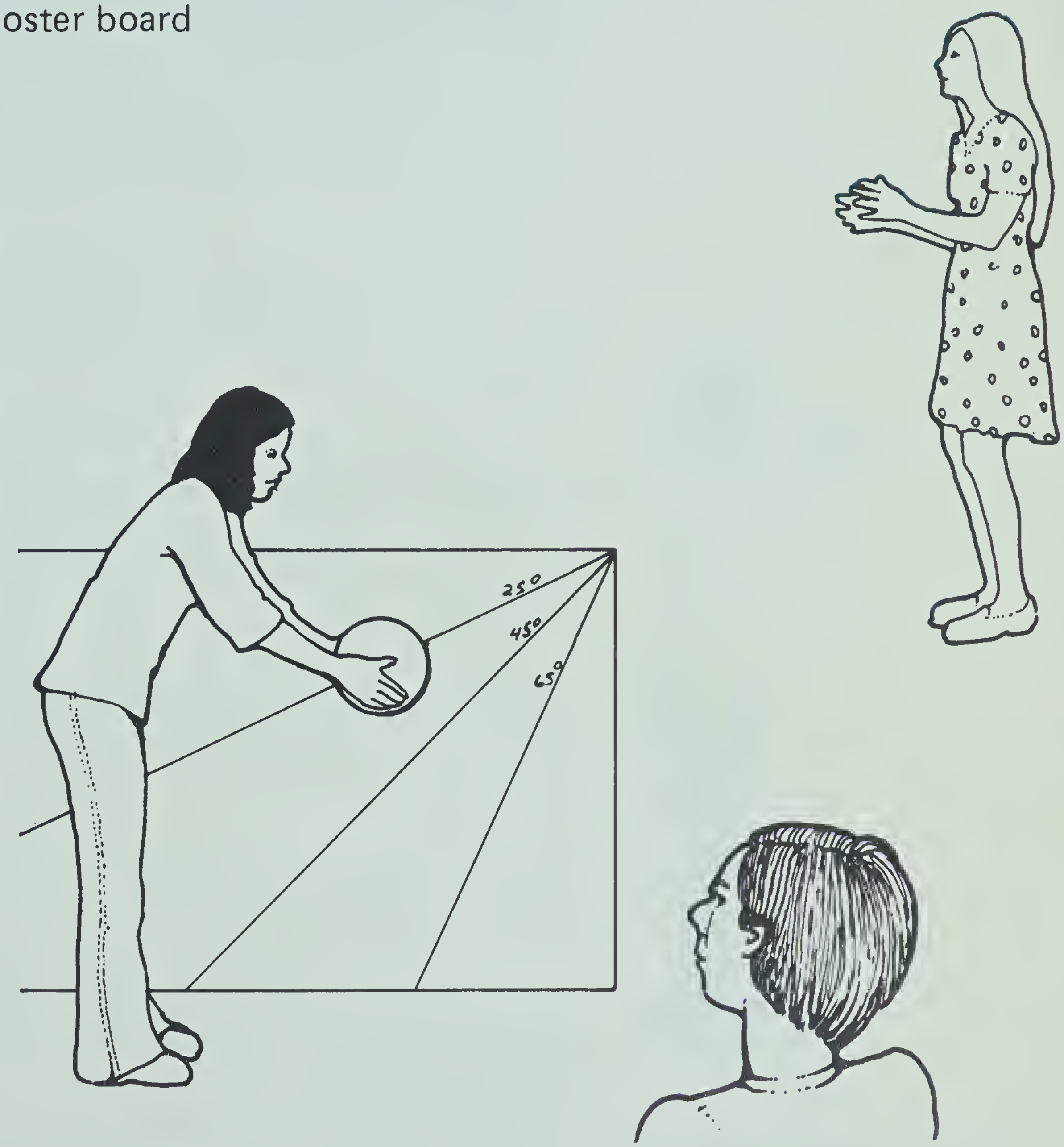
If time permits and your teacher is willing, you could try applying what you've learned. You'll need two partners, at least ten minutes, and the following materials.

While difficult to do, this exercise can drive home the concept of the correct angle of projection.

soccer ball, volleyball, or basketball
large piece of cardboard or poster board
protractor

A. Using the protractor for measuring, draw lines on the cardboard at the angles shown.

B. Make sure you have plenty of room. Then station yourself between the cardboard and one of your partners as shown. Toss the ball underhanded to your other partner, using both hands. Make several throws at different angles, trying to keep the ball's speed the same. Your observing partner can check the angles.



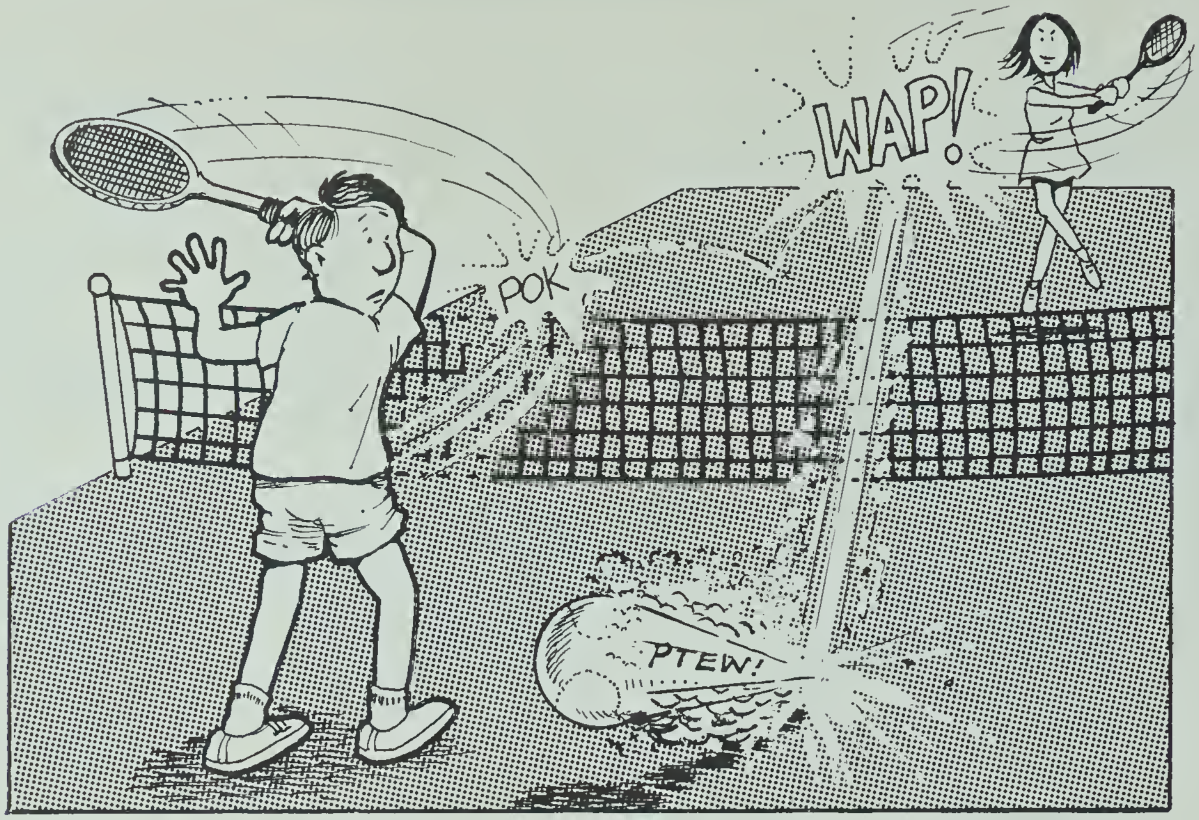
• 14-17. At which angle did you get maximum range?

14-17. 45°

ACTIVITY EMPHASIS: The total amount of energy involved in a collision remains constant. After an elastic collision, the amount of kinetic energy is the same as before the collision. After an inelastic collision, the amount of kinetic energy is less than before the collision, because some energy remains in other forms.

MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter.

ACTIVITY 15: ENERGY AND ELASTICITY



If you have watched tennis matches or golf tournaments on TV, you have probably seen lots of commercials that advertise tennis balls and golf balls. What do all those commercials have in common?

One thing they seem to share is the claim that their particular brand of ball will go faster and farther when you hit it. In terms of the physics of sport, manufacturers are selling increased *elasticity*.

In Activity 3 you saw that balls of different kinds vary in their degree of elasticity. When dropped from a 2-m height, balls of different sorts bounce back to measurably different levels. Among commonly used sports balls, golf balls have the highest rebound height.

Get a golf ball and take it to some place with a concrete or asphalt surface (a sidewalk would be fine). Hold the ball away from you at eye level and then drop it. Watch how high it rebounds.

- 15-1. Did the ball bounce all the way back to eye level?

15-1. No

If the ball had bounced all the way back, its collision with the surface would have been perfectly elastic. Such perfection seldom occurs in sports or elsewhere. Some collisions, however, come fairly close.

The energy possessed by an object in motion is called *kinetic energy*. In a perfectly elastic collison, the kinetic energy in the system is the same before and after.

The USGA actually limits the elasticity of sanctioned balls as a means of preserving the challenge of existing golf courses.

PERFECTLY ELASTIC COLLISION

kinetic energy before collision	=	kinetic energy after collision

Total energy remains the same.

You can calculate the kinetic energy of an object by multiplying half its mass by the square of its speed. Take, for example, a golf ball with a mass of 0.046 kg that is moving at 42 m/s. E_k stands for kinetic energy; J stands for *joule*. A joule is a unit of energy equal to 1 N · m, or 1 kg $(m/s)^2$. The formula for kinetic energy is expressed as follows.

$$E_k = \tfrac{1}{2}\,(\text{mass})(\text{velocity})^2 = \tfrac{1}{2}\,mv^2$$

Let's take this step by step:

$$E_k = \frac{(\text{mass})(\text{velocity})^2}{2}$$

$$= \frac{(0.046\ \text{kg})(42\ \text{m/s})^2}{2}$$

$$= \frac{(0.046\ \text{kg})(1764)(\text{m/s})^2}{2}$$

$$= \frac{81.144\ \text{kg}\ (\text{m/s})^2}{2}$$

$$= 40.572\ \text{kg}\ (\text{m/s})^2$$

$$= 41\ \text{J}$$

• 15-2. If the golf ball could collide perfectly elastically with a stone wall, how much kinetic energy would it have after the collision, and how fast would it be traveling?

15-2. 41 J; 42 m/s

Probably the closest example to an elastic collision in sports is a dead-center collision of two pool balls. In Figure 15-1 below, the elapsed time between frames is the same. The distance traveled by the seven ball before collision (60 mm per frame) is matched by that of the eight ball after the collision. (This shows they had equal velocity.) And the two balls have equal mass. Suppose the seven ball had 0.8 J of kinetic energy before the collision.

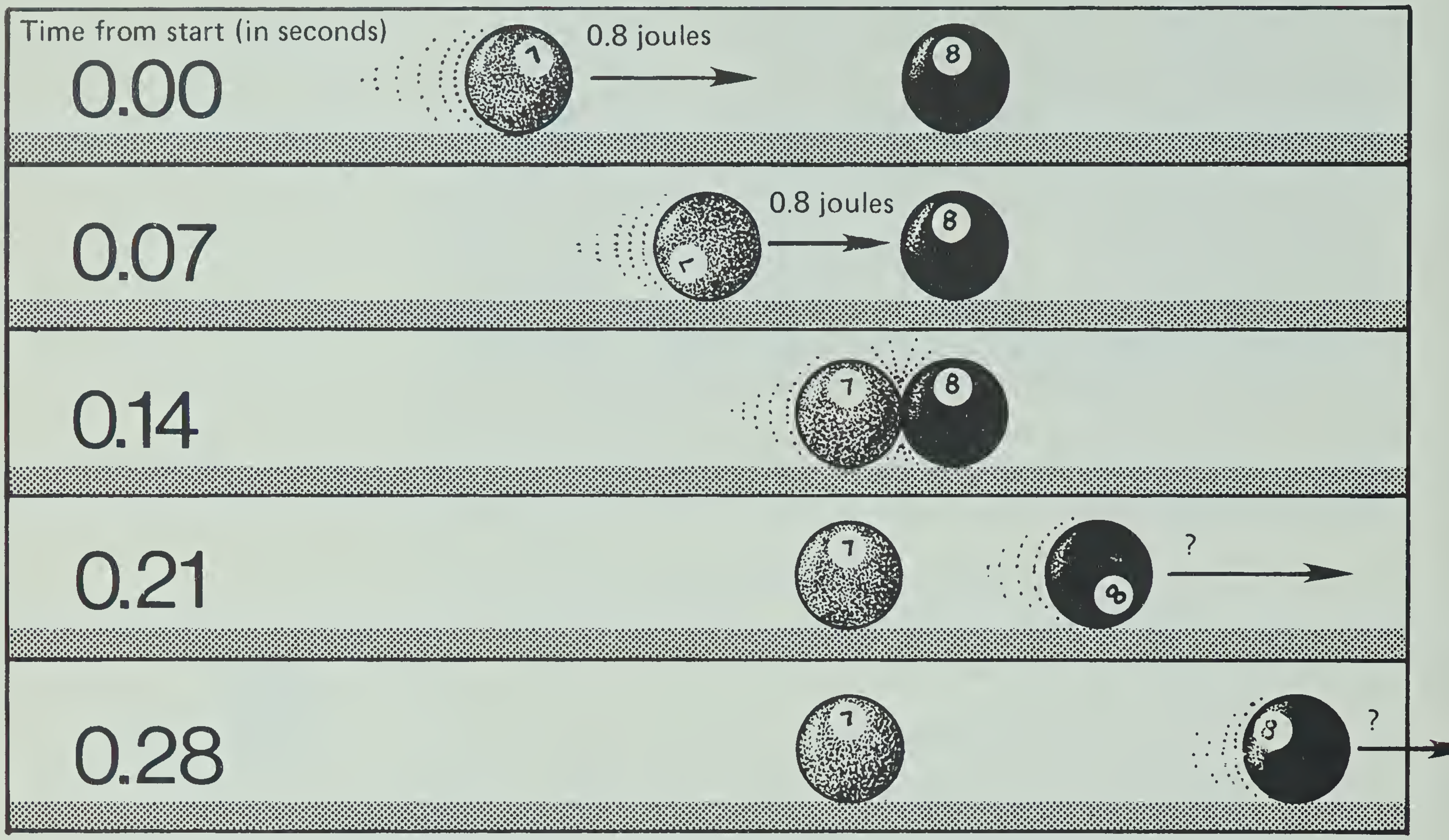


Figure 15-1

15-3. The energy a body has because of its motion.

☆ **15-3. What is kinetic energy?**

15-4. None

• 15-4. How much kinetic energy did the eight ball have before the collision?

15-5. 0.8 J

• 15-5. What was the total kinetic energy before the collision?

15-6. None (nearly)

15-6. How much kinetic energy did the seven ball have after the collision?

15-7. 0.8 J (almost)

☆ **15-7. What was the kinetic energy of the eight ball after the collision?**

15-8. It is a collision in which the kinetic energy before and after the collision is the same.

☆ **15-8. What is meant by the term "elastic collision"?**

When a ball collides with another object, it is temporarily compressed out of shape. Figure 15-2 at right shows a tennis ball striking the surface of a court.

- 15-9. At what position is the ball compressed?

- 15-10. At what position will the ball be moving slowest and have the least kinetic energy?

- 15-11. At what numbered position has the ball first regained its kinetic energy after being compressed?

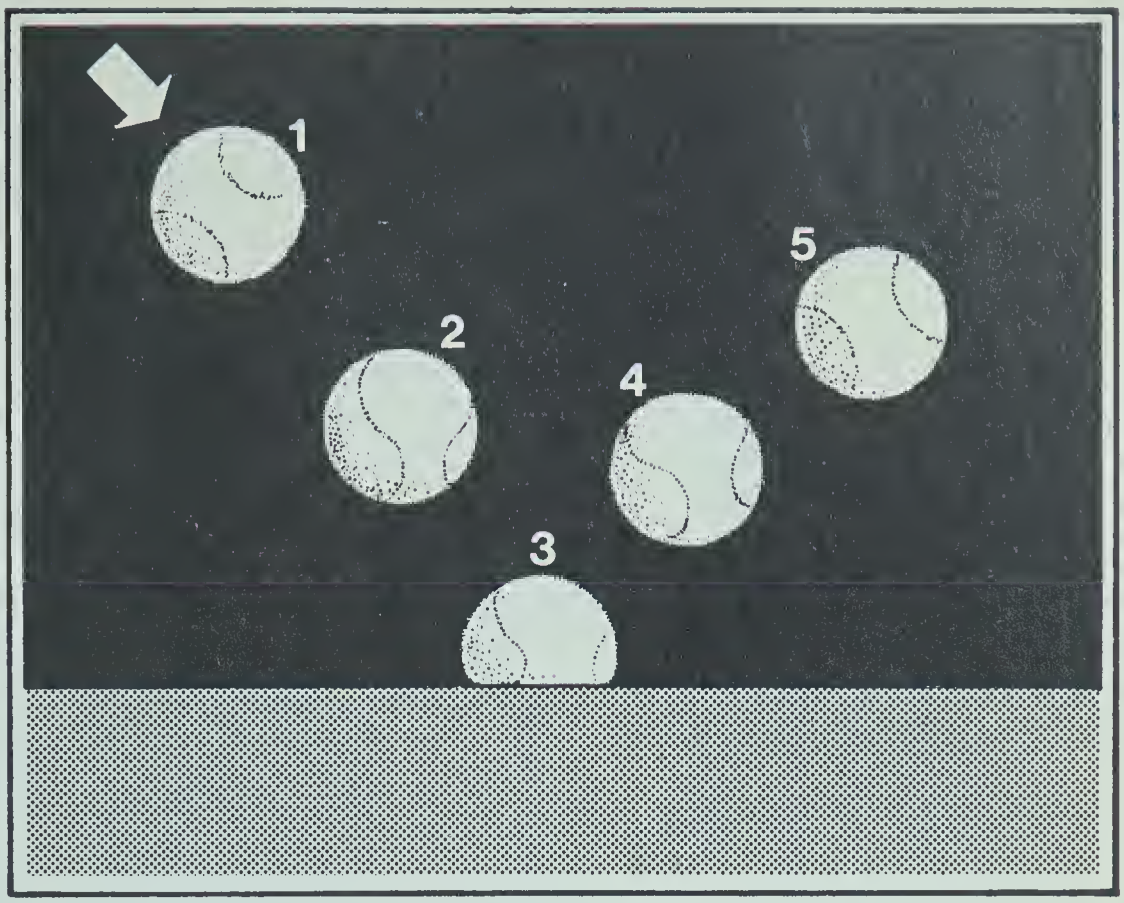


Figure 15-2

During the time of compression, the kinetic energy of the ball was reduced. But most of this energy was regained as the ball recovered its shape. Had the collision been perfectly elastic, the ball would have regained all its original kinetic energy. Figure 15-3 below shows the actual result.

15-9. 3

15-10. 3

15-11. 4

INELASTIC COLLISION

kinetic energy before collision	=	kinetic energy after collision	+	heat

Total energy remains the same.

Figure 15-3

If a collision is not perfectly elastic, it is inelastic. All the balls you normally use in sports participate only in inelastic collisions (although some are more inelastic than others). In the case of the tennis ball in Figure 15-2 at the top of the page, some of the kinetic energy was converted to heat by the collision. This is an example of one of the most important laws of science.

Energy cannot be created or destroyed. Although it may be transformed from one form into another, the total amount of energy in a system doesn't change. This great generalization is known as the *law of conservation of energy.*

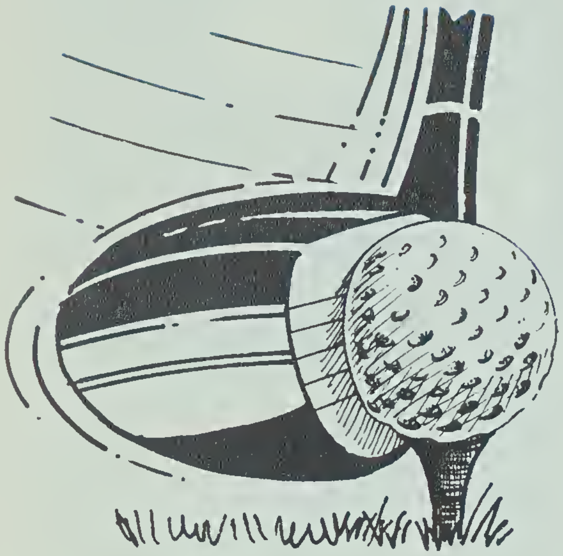
The law of conservation of energy can be considered a cornerstone of science.

☆ **15-12. What happens to kinetic energy as a result of a perfectly elastic collision?**

15-12. The amount of kinetic energy is unchanged by a perfectly elastic collision.

☆ **15-13. What happens to kinetic energy as a result of an inelastic collision?**

15-13. Some of it is changed to other forms of energy.



So far, we have described the energy states before and after collisions. But what about *during* the collision? Questions 15-10 and 15-11 on page 67 imply that at the moment of collision there is somehow less kinetic energy in the system than there has been before or will be afterward. If energy is always conserved, how can this be?

The law of conservation of energy suggests that this "missing" energy must have been changed to another form. Thus the change of a ball from its normal shape is associated with an increase in *potential (stored) energy*. When the ball has recovered its shape, this potential energy has been converted back to kinetic energy. If the collision is perfectly elastic, then the kinetic energy the ball had before the collision is converted into potential energy during the collision and converted back to kinetic energy afterward.

But suppose the collision is not perfectly elastic. Then, during the collision, some of the kinetic energy is converted to heat and the rest to potential energy. The heat is not converted back to kinetic energy. This is why the kinetic energy after such an inelastic collision is less than the kinetic energy before the collision. According to physicist C.B. Daish, the temperature of a golf ball is increased about 0.5°C when it is hit with a driver.

The potential energy in the compression of a ball is similar to the stored energy in a watch spring.

☆ **15-14. What is the difference between an elastic and an inelastic collision?**

15-14. In an elastic collision, the kinetic energy is the same before and after the collision; in an inelastic collision, some of the kinetic energy is changed to heat energy.

☆ **15-15. Why do tennis and squash balls get noticeably warmer during a game?**

15-15. Because some of their kinetic energy has changed to heat

In contact sports, players collide with each other and with playing surfaces. They need protective equipment.

• 15-16. To protect a player during a collision, what should protective equipment do to the kinetic energy the player had before the collision?

15-16. It should change it to heat and other less harmful forms of energy. .

ACTIVITY 16: COLLISIONS

ACTIVITY EMPHASIS: The total momentum of all involved bodies before a collision is equaled by their total momentum after the collision. Momentum (mass X velocity) is conserved.

MATERIALS PER STUDENT LAB GROUP: None

If you've ever played golf or watched a golf game in person or on TV, you know that golf balls can travel very fast. From a standing start on tee or ground, they achieve high velocities as soon as they are struck. They get moving so fast, in fact, that even on the TV "stop-action" devices they look like blurry white lines. That's fast.

But how fast is this exactly? Faster than a baseball? A racing car? A speeding bullet? There's a way to find out.

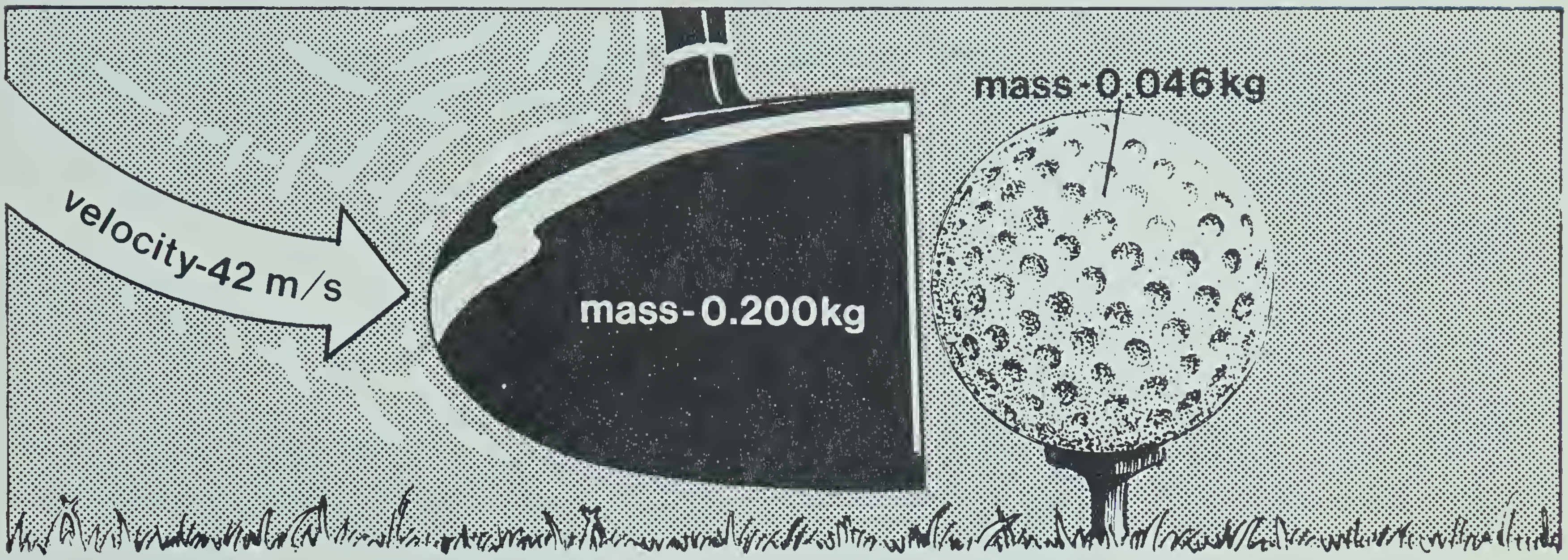


Figure 16-1

The golf club in Figure 16-1 above is about to hit the ball. When you know the mass and velocity of the clubhead, as well as the mass of the ball, you can figure out what the ball's velocity will be after it is struck. The key is the *momentum* of the ball and the clubhead before and after collision. Momentum is the special name given to the product of the mass and the velocity of any object.

MOMENTUM = MASS (m) *times* VELOCITY ($\vec{v}$)

Although both may be expressed in kg, mass and weight are not the same. Weight is the gravitational force exerted on a body. Mass is a measure of a body's inertia.

The mass (m) of an object is its amount of matter. The velocity ($\vec{v}$) of an object is both its speed (distance traveled divided by time required) and its direction of motion. The arrow (→) over the v reminds us that velocity has direction.

The golf ball in Figure 16-1 above has a mass of 0.046 kg. Its velocity is zero while it rests on the tee. You can find the momentum of the ball on the tee by applying the formula.

$$
\begin{aligned}
\text{Momentum} &= m\vec{v} \\
&= (0.046\ \text{kg})(0\ \text{m/s}) \\
&= 0\ \text{kg m/s}
\end{aligned}
$$

Notice that the ball's momentum is zero because it is at rest (has zero velocity). Also notice that the unit of momentum is *kg m/s*. That comes from multiplying the unit of mass (kg) by the unit of velocity (m/s).

Now calculate the momentum of the clubhead in Figure 16-1 (page 69). The clubhead has a mass of 0.200 kg and a velocity of 42 m/s.

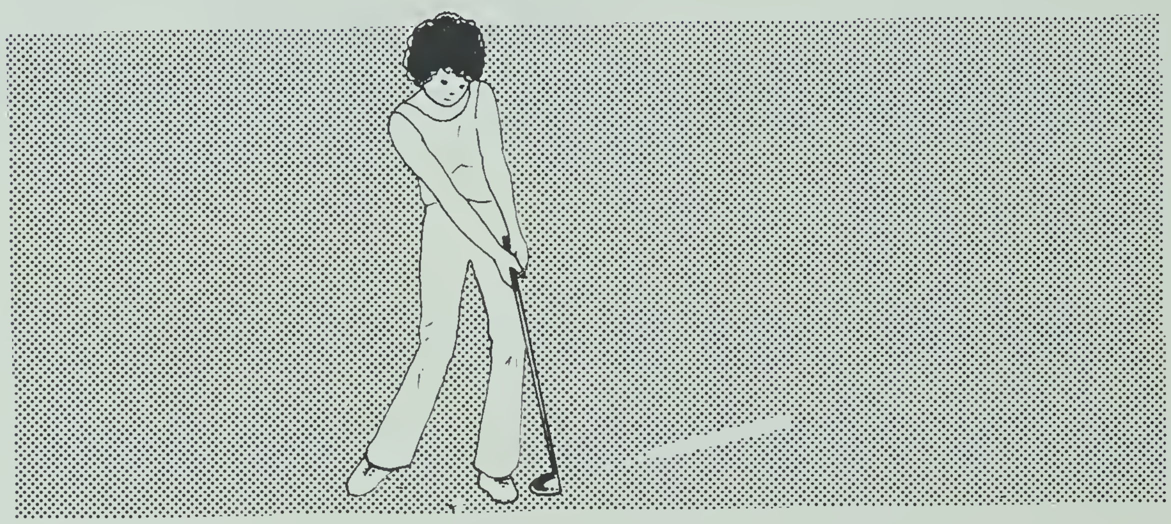
16-1. 8.4 kg m/s

● 16-1. What is the momentum of the clubhead? (Don't forget that the proper unit designation is important to a correct answer.)

16-2. Mass times velocity [Answers may vary.]

☆ **16-2. Define momentum.**

The golf ball's momentum will jump up from zero when the clubhead sends it flying down the fairway.



16-3. It's in motion; velocity isn't zero now.

● 16-3. Why will the golf ball's momentum not be zero now?

About three hundred years ago, the English scientist Sir Isaac Newton studied the motion of objects. From his discoveries, later scientists formulated a law that applies to all colliding bodies. It's the same for footballs and golf balls, cars and ships, atoms and molecules, or meteors and moons.

Note that the law holds true in all collisions, both elastic and inelastic.

This law, the *law of conservation of momentum*, states that the total momentum of all the bodies just before collision is equal to the total momentum of all the bodies just after collision. The law as it applies to the collision of two objects is displayed at the top of page 71.

CONSERVATION OF MOMENTUM

$$\overbrace{\boxed{\text{Momentum of Object 1} \quad (m_1\vec{v}_1)} + \boxed{\text{Momentum of Object 2} \quad (m_2\vec{v}_2)}}^{\text{Total momentum before collision}} = \overbrace{\boxed{\text{Momentum of Object 1} \quad (m_1\vec{v}_1')} + \boxed{\text{Momentum of Object 2} \quad (m_2\vec{v}_2')}}^{\text{Total momentum after collision}}$$

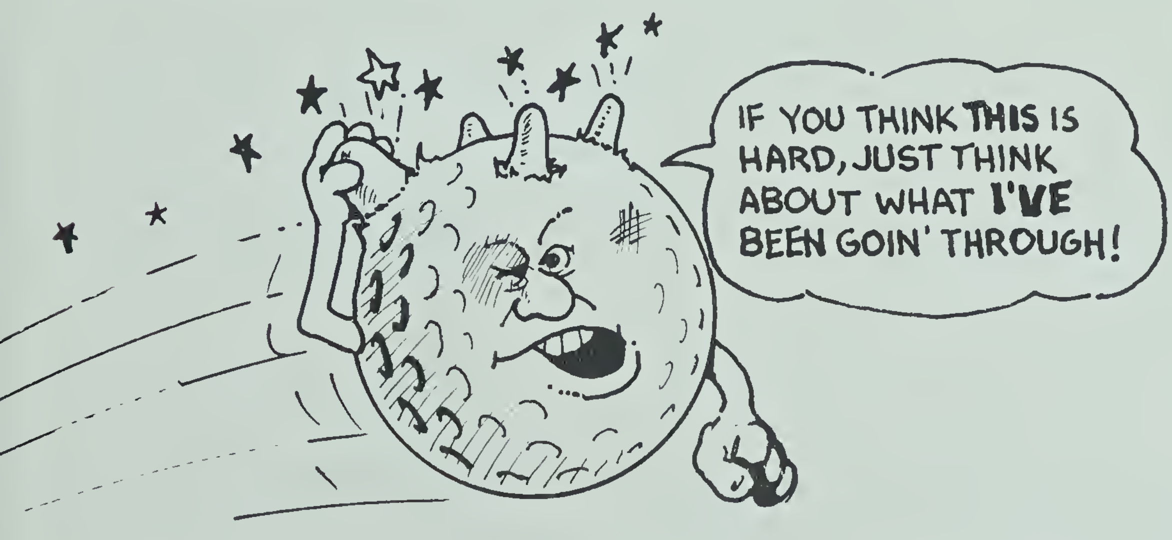
Now let's use the law of conservation of momentum, and some information about the velocity of the clubhead, to find the post-collision velocity of the golf ball in Figure 16-1 (page 69).

ball's momentum before collision	+	clubhead's momentum before collision	=	total momentum before collision
$m_1\vec{v}_1$	+	$m_2\vec{v}_2$		
(0.046 kg)(0 m/s)	+	(0.200 kg)(42 m/s)		
0 kg m/s	+	8.4 kg m/s	=	8.4 kg m/s

The law says that momentum is conserved. Therefore, the total momentum after the clubhead strikes the ball must also be 8.4 kg m/s. This is the momentum of the ball and the clubhead combined.

It's already known that the mass of the clubhead is 0.200 kg and the mass of the ball is 0.046 kg. These values have not been changed by the collision. The remaining unknowns are the post-collision velocities of the clubhead and the ball. If one of these velocities can be learned, the other can be figured out.

Momentum is conserved only if there is zero net external impulse in the system. In other words, we are making the assumption that the golfer is not adding impulse to the clubhead during the time of impact with the ball. This is not strictly true, but the time of impact is very short.



From studying high-speed motion pictures, scientists have been able to chart the velocity of the clubhead at various points in the swing. Figure 16-2 on page 72 shows this information.

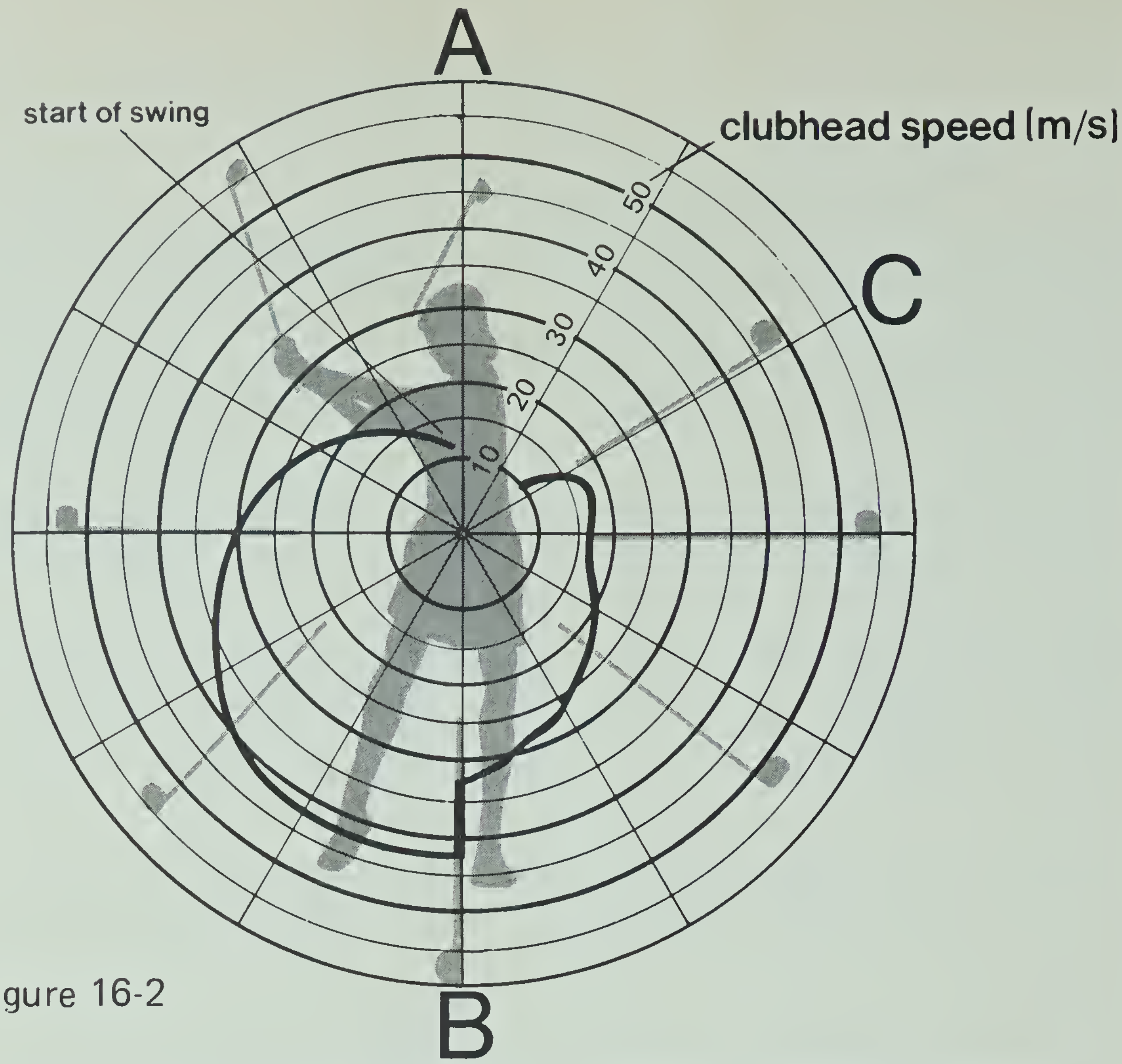


Figure 16-2

The point of collision between clubhead and ball is shown at Point B. The arc between Points A and B shows clubhead speed during the downswing. The arc from Points B to C shows the speed of the clubhead after impact – during the "follow-through." You can read off the speed of the clubhead at any point in the swing by noting the value (in m/s) of the circling line that the clubhead's path is intercepting at that point.

16-4. About 42 m/s

• 16-4. Just before collision with the ball, what was the speed of the clubhead?

16-5. Between 32 m/s and 33 m/s

• 16-5. Just after the collision, what was the speed of the clubhead?

You need the answer to Question 16-5 above in order to compute the speed of the ball.

ball's momentum after collision	+	clubhead's momentum after collision	=	total momentum after collision
$m_1\vec{v}_1'$	+	$m_2\vec{v}_2'$		
(0.046 kg) (? m/s)	+	(0.200 kg) (32 m/s)	=	8.4 kg m/s

"? m/s" is the ball's speed. That's the unknown. It will be represented by V in the solution below.

$$\begin{aligned}
\boxed{\begin{array}{l}\text{total momentum}\\ \text{before collision}\end{array}} &= \boxed{\begin{array}{l}\text{total momentum}\\ \text{after collision}\end{array}}\\
8.4 \text{ kg m/s} &= 0.046 \text{ V} + 6.4 \text{ kg m/s}\\
8.4 \text{ kg m/s} - 6.4 \text{ kg m/s} &= 0.046 \text{ V}\\
2.0 \text{ kg m/s} &= 0.046 \text{ V}\\
\frac{2.0 \text{ kg m/s}}{0.046} &= \text{V}\\
43.5 \text{ m/s} &= \text{V}\\
\text{V} &= 43.5 \text{ m/s}
\end{aligned}$$

Note that since the mass of the ball was less than the mass of the club, it could be given a velocity greater than that of the club.

Let's review what happened during the collision.

- 16-6. What was the momentum of the clubhead before it struck the ball?
- 16-7. What was the momentum of the ball before it was struck?
- 16-8. When the clubhead struck the ball, what happened to the clubhead's momentum? How do you know?
- 16-9. Since the law of conservation of momentum says that the total momentum in a system (in this case, clubhead + golf ball) does not change, what happened to the momentum that was lost by the clubhead?
- 16-10. Explain what is meant by the law of conservation of momentum.

☆ 16-11. Suppose a golf ball is struck by a club swung at 30 m/s. The ball's mass is 0.05 kg, the club's mass is 0.2 kg, and the club is traveling 20 m/s just after collision. What is the momentum of the club before collision? After collision? What is the momentum of the ball before collision? After collision?

16-6. 8.4 kg m/s

16-7. 0

16-8. The momentum decreased; it must have decreased, because the charted velocity of the clubhead decreased.

16-9. It was transferred to the golf ball.

16-10. When bodies collide, the total momentum of all the bodies before collision is equaled by their total momentum after collision.

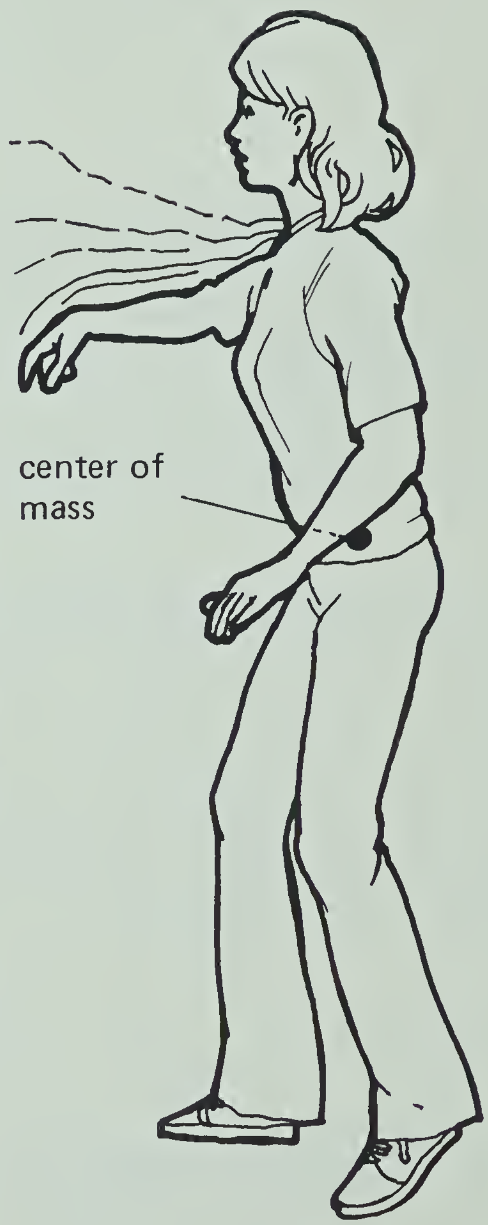
16-11. The club's momentum is 6 kg m/s before collision and 4 kg m/s after; the ball's momentum is 0 kg m/s before collision and 2 kg m/s after.

Excursion

ACTIVITY 17: PLANNING

You and a partner can help each other locate your centers of mass. You'll also see how your center of mass shifts as you change your posture. And you may discover one more difference between males and females.

A football can spiral, a fastball can hop, and a golf ball can back up. These aren't dances. They are the behaviors of sports balls being influenced by special spins. This activity shows you what spins you can use and what effects they can produce.



Success in sports often depends on coordination of mind and body. Everyday actions may also call for quick responses. This activity measures one feature of coordination — your reaction time.

ACTIVITY 18: FINDING THE CENTER OF MASS

ACTIVITY EMPHASIS: Physical measurements can be used to determine a person's center of mass.

MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter.

Do you remember what the *center of mass* is? In Activity 9 it was defined as an imaginary point where you might consider an object's weight to be concentrated.

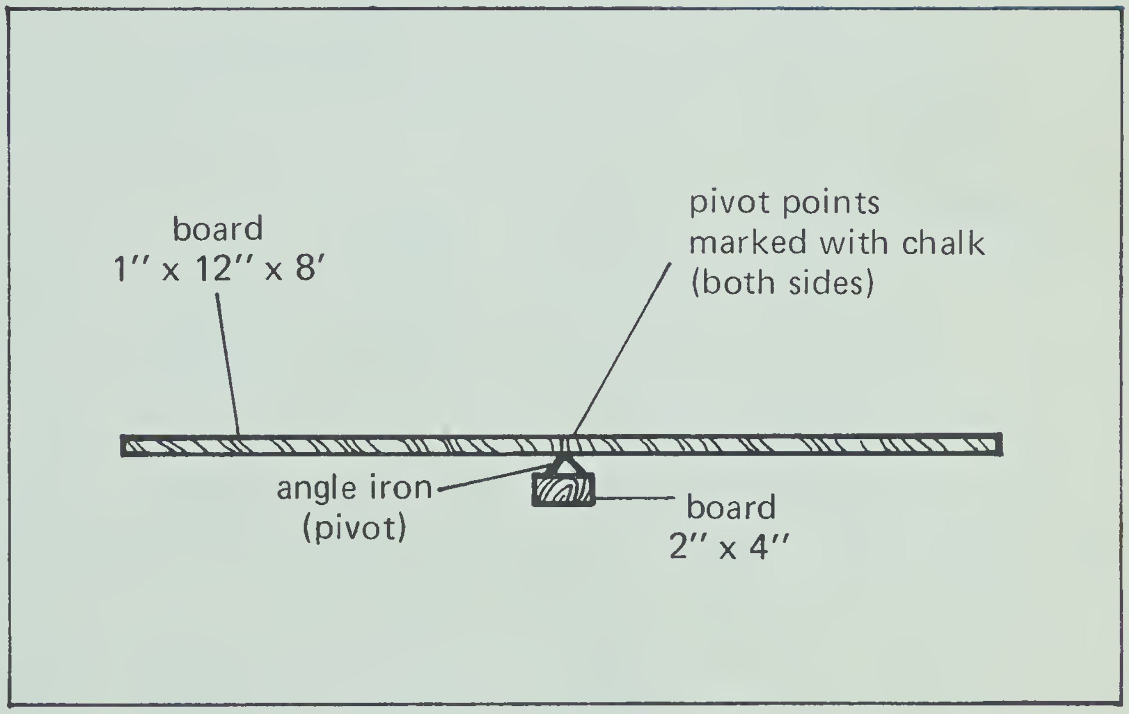
Any object balances on its support only when its center of mass (CM) is either directly above or directly below that support. If the CM is off to the side of the support, the object will topple over or turn. This fact makes it possible to determine an object's CM by using the balance method.

Try this investigation to determine the placement of a person's CM. You will need a partner, about twenty minutes, and the following materials.

angle iron (for a pivot)
board, 2″ X 4″ X 18″
finished board, 1″ X 12″ X 8′
chalk
metre stick or (metric) measuring tape

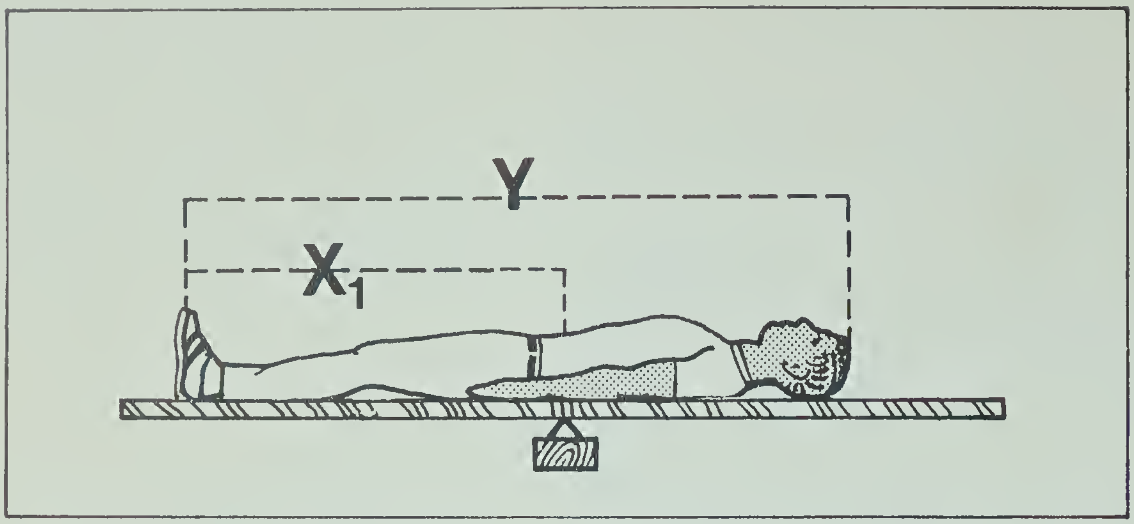
The 1″ X 12″ should be polished wood to avoid a harvest of splinters by partner.

A. Set the angle iron on the short board to avoid scratching the floor. Then place the long board on the angle iron as shown, so that it balances. With the chalk, mark the edges of the balancing board at the exact point of balance. **It is important that these marks remain above the pivot point throughout the activity.** That way the CM of the board will stay right there, and all changes in balance will result from changes in your partner's CM.



B. Copy this table in your notebook. It will be used for recording the measurements you will need for your calculations. There is only one space for Y because a person's height is considered constant (nobody grows that fast).

	FROM FEET TO PIVOT (m)	HEIGHT (m)
Lying flat, arms at sides	X_1:	
Lying flat, arms above head	X_2:	Y:
Knees bent, arms at sides	X_3:	



C. Have your partner lie on the board and then slide along it until in balance. Using the metre stick or tape, measure the distance from the bottom of your partner's feet to the pivot point. This is X_1. Then measure the height of your partner. This is Y. Record the measurements in your notebook.

from partner's feet to pivot

partner's CM is this % of height above ground

$$\frac{X}{Y} \times 100\% = \_\_\_\_ \%$$

partner's height

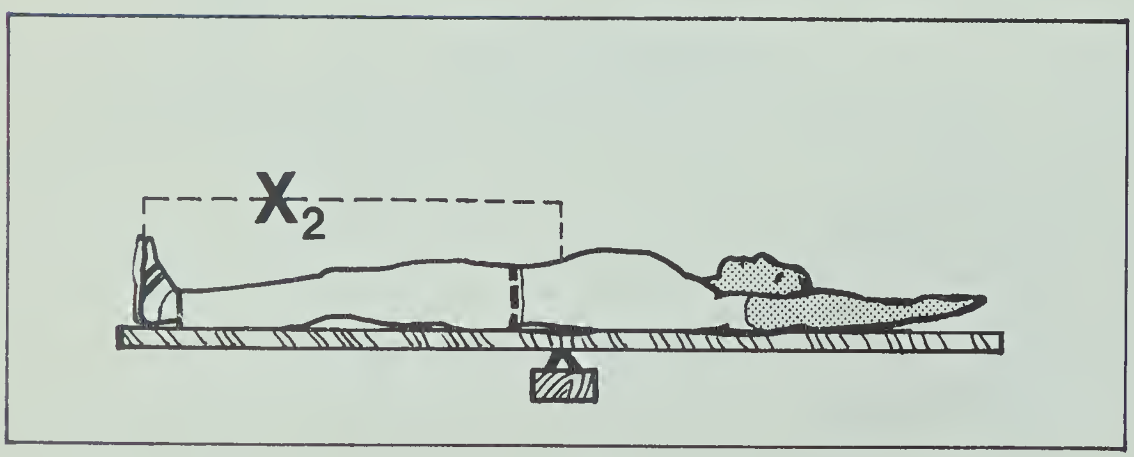
D. Figure your partner's CM by inserting your figures for X_1 and Y into the formula at left. The resulting number tells you what percentage of your partner's height is between his or her feet and the CM. For example, if your partner is 1.80 m tall, that would be the value of Y. And if the center of mass is 1.02 m above the feet, that would be the value of X_1. Then

$$\frac{1.02}{1.80} \times 100\% = 56.6\%$$

18-1. [Answers will vary — usually 55% to 57%.]

• 18-1. What percentage of your partner's height is between feet and CM?

Your center of mass changes when you shorten or lengthen your body's extension.



E. Have your partner raise both arms above his or her head. Redetermine the balance position, and measure the new foot-to-pivot distance, X_2. Be sure that the two chalk marks on the board line up with the pivot when your partner is balanced.

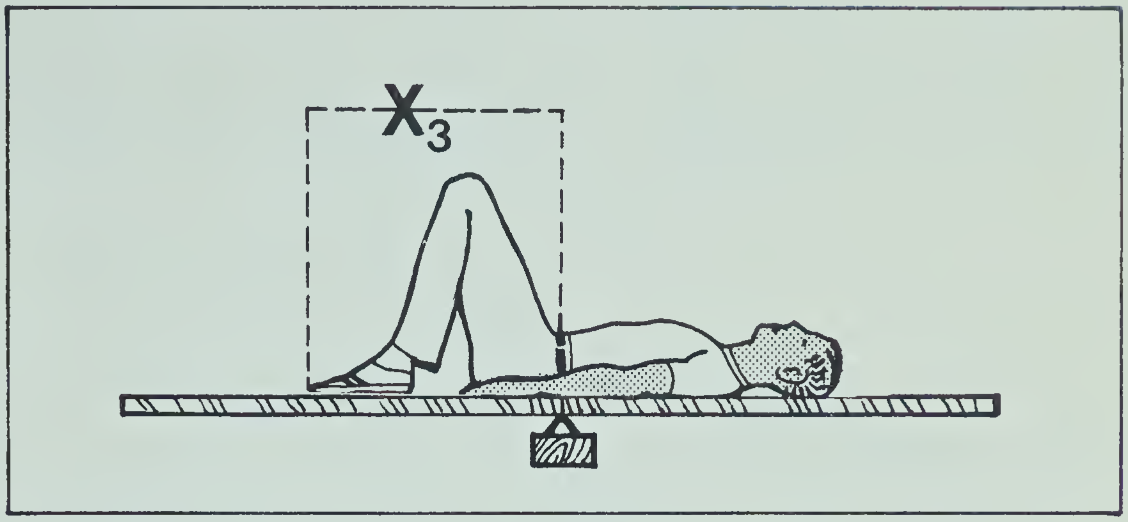
• 18-2. What percentage of your partner's height is between the CM and the feet now?

18-2. [Answers will vary — probably 60%.]

☆ **18-3. If you raise your arms above your head when standing, what happens to your center of mass?**

18-3. It is raised.

F. Have your partner raise his or her knees. Redetermine the balance position, and measure the foot-to-pivot distance, X_3. Calculate the percentage of the height as before.

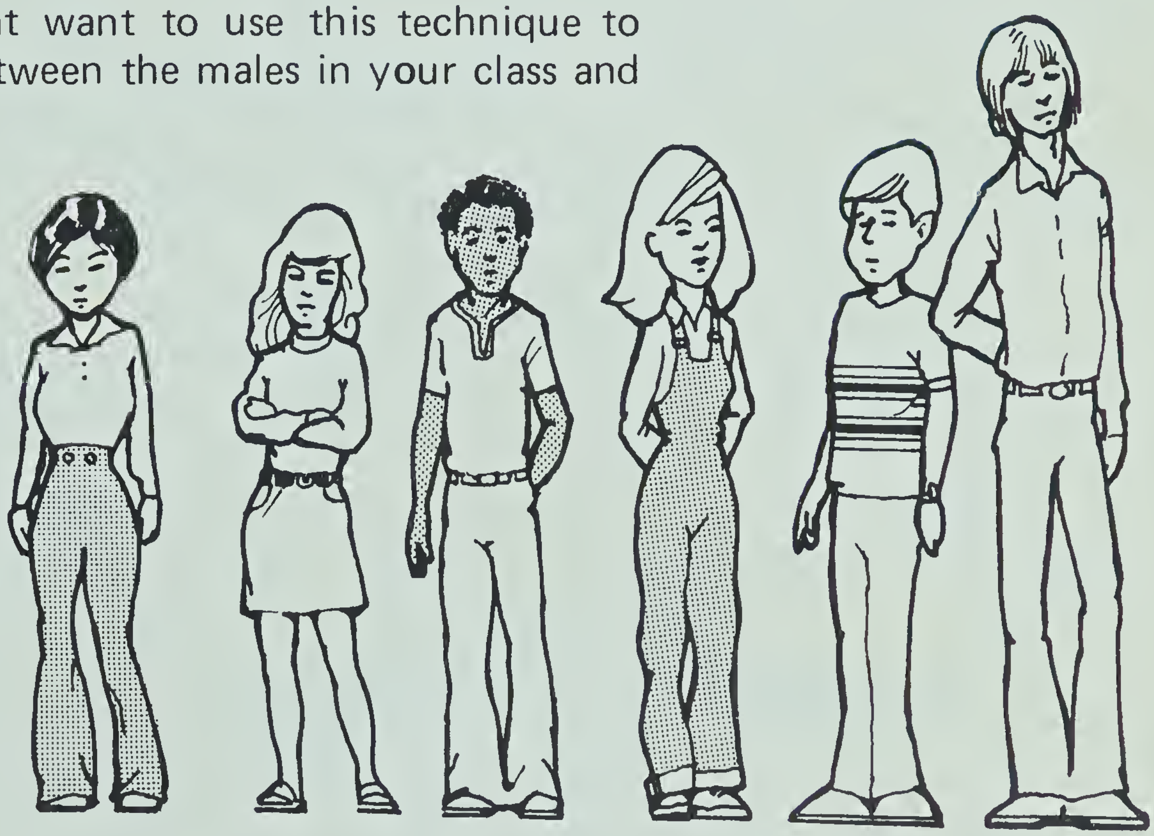


☆ **18-4. If you crouch or squat down, what happens to your center of mass?**

18-4. It is lowered.

Time permitting, you might want to use this technique to investigate how CM differs between the males in your class and the females.

G. Select three people of each sex. Using each as a subject, repeat Steps C and D, so that you have a percentage figure ($X_1/Y \times 100\%$) for each. Average the percentages for males. Average the percentage for females.



• 18-5. According to your data, which group has a lower average CM, males or females?

18-5. [Answers may vary, but usually females have lower centers of mass.]

Although individuals vary greatly, the data on large numbers of people put the center of mass for males at an average of 56% to 57% of their height. For females the average is about 55% of their height — about 1% to 2% lower than for males.

ACTIVITY EMPHASIS: Proper spin on a nonspherical ball can give it some stability. Also, backspin, topspin, and sidespin can all be used to advantage in a variety of sports.

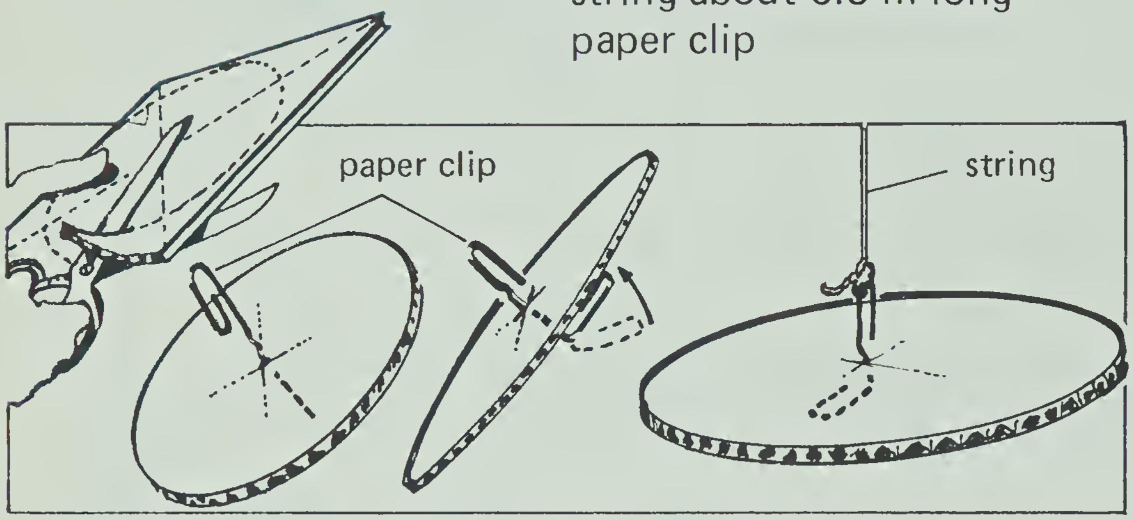
MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter. See "Advance Preparations" in ATE front matter.

ACTIVITY 19: THE USES OF SPIN

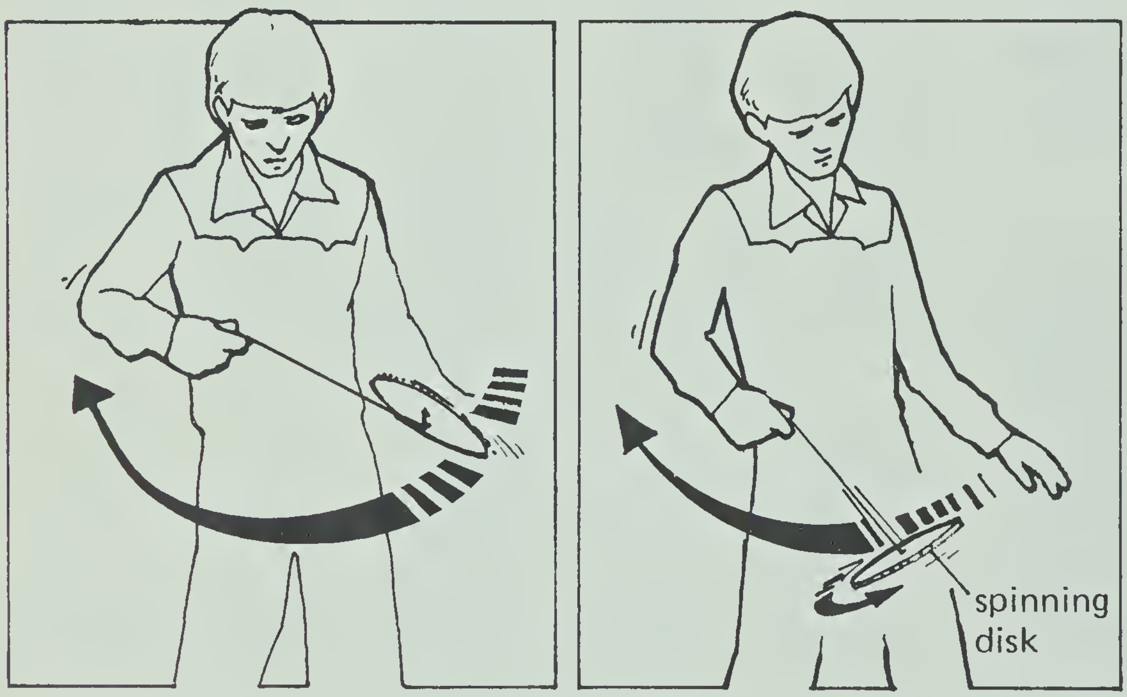
A baseball can be made to curve in flight if it is spinning. This is true of other round balls like golf balls, tennis balls, and basketballs. And, as you will see, spin has its uses after the ball strikes a surface. But there is another effect of spin called *stability*. Spin can make quite a difference in the flight path of a football or any other object that is not a perfect sphere.

To investigate the stability that results from spin, you will need ten minutes and the following materials.

corrugated cardboard 20 cm X 20 cm
scissors
string about 0.5 m long
paper clip



A. Round off the cardboard to make a circular disk. Half straighten the paper clip and punch it through the center of the disk. Bend the open end back around to form a loop. Tie one end of the string to the paper clip.



B. Hold the other end of the string in one hand. Without spinning the disk, swing it back and forth like a pendulum. Observe whether the disk has a stable attitude or whether it tumbles around.

C. Now, with your free hand, spin the disk as fast as you can about its paper-clip axle. Then quickly swing it as before. Again observe whether the disk's attitude is stable or not.

19-1. It tumbled around; it swung, while spinning, in a stable attitude.

• 19-1. During Step B, did the disk swing in a stable attitude with respect to the floor, or did it tumble around? How about during Step C?

19-2. It began to tumble again.

• 19-2. What happened, in Step C, when the spinning motion began to slow up?

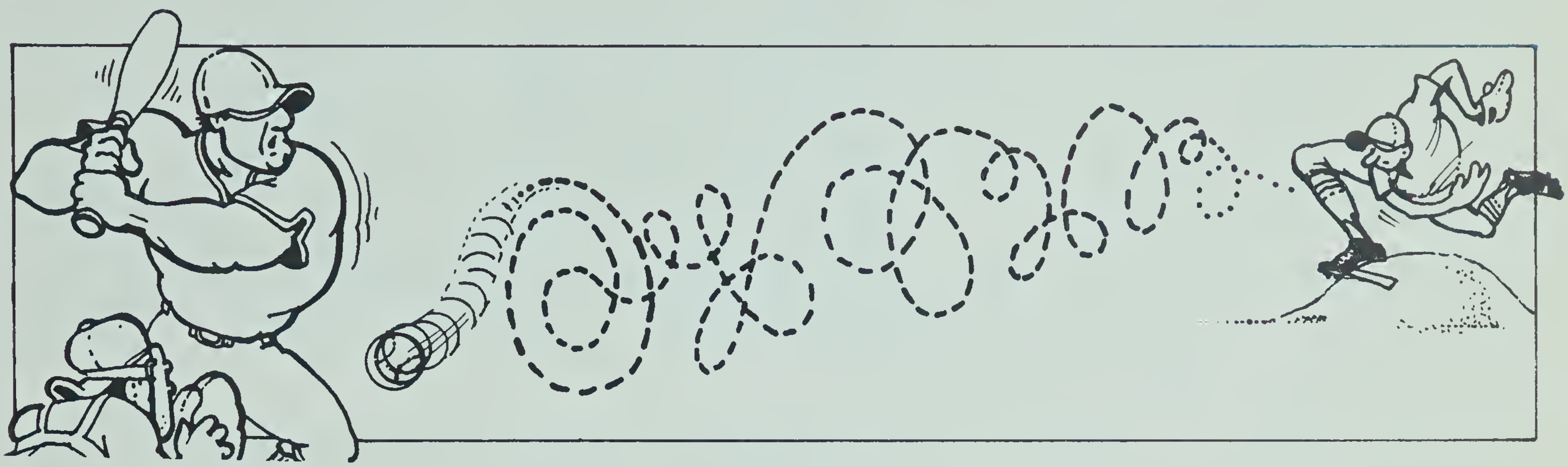
If a football is available, you may wish to try tossing it gently to a partner. Try to throw it without any spin about its longitudinal axis (a "wounded duck"). Then try to throw it with spin (a "spiral").

• 19-3. What happens to a football thrown without spin compared to one thrown with spin?

19-3. It tends to tumble or wobble in flight.

• 19-4. What are some disadvantages of throwing a football so that it tumbles end over end?

19-4. You get less accuracy and distance, and the ball is harder to catch.



In baseball, the pitcher wants to make his tosses hard to hit.

"Dear Ma," wrote the rookie from training camp, "Today in batting practice they starting throwing curves. I guess I'll be home in a few days."

Some hitters can't handle curves. Others can. But every batter has trouble with knuckleballs. And so do catchers. The problem with the knuckler is that nobody knows where it's going, not even the pitcher who throws it. It seems to come to the plate dancing on air like a butterfly. Sometimes it drops. Sometimes it curves or rises. Often it just seems to wiggle back and forth.

Wind tunnel studies have shown why knuckleballs behave as they do. Their unpredictability is due to the fact that a baseball is not truly round. It has raised seams on it. These form an irregular surface that meets the oncoming air in an irregular way. If a baseball is pitched without any spin, the irregularity of the ball's surface will make the ball swerve off course. The direction of swerve depends on just how the seams of the ball are lined up with the direction of flight.

A knuckleball that flutters is one that is rotating very slowly (about a quarter turn between pitcher's mound and home plate). When the seams change position very slowly, they cause the ball to swerve first one way and then another. Like a football, then, a baseball needs a certain amount of spin for stability.

This is probably a more effective pitch than a totally spinless knuckler, since it can be kept in or near the strike zone while remaining nearly impossible to hit.

19-5. Curveball (most spin), straight ball (some spin), knuckleball (little if any spin)

● 19-5. Rank these pitches from highest to lowest according to the amount of spin on each — curveball, knuckleball, straight ball.

Spin on a ball not only affects the ball's flight path, it also affects what happens to the ball at the end of flight. When a spinning golf ball hits the ground, for example, it tends to behave in one of two ways. Look at Figure 19-1 below.

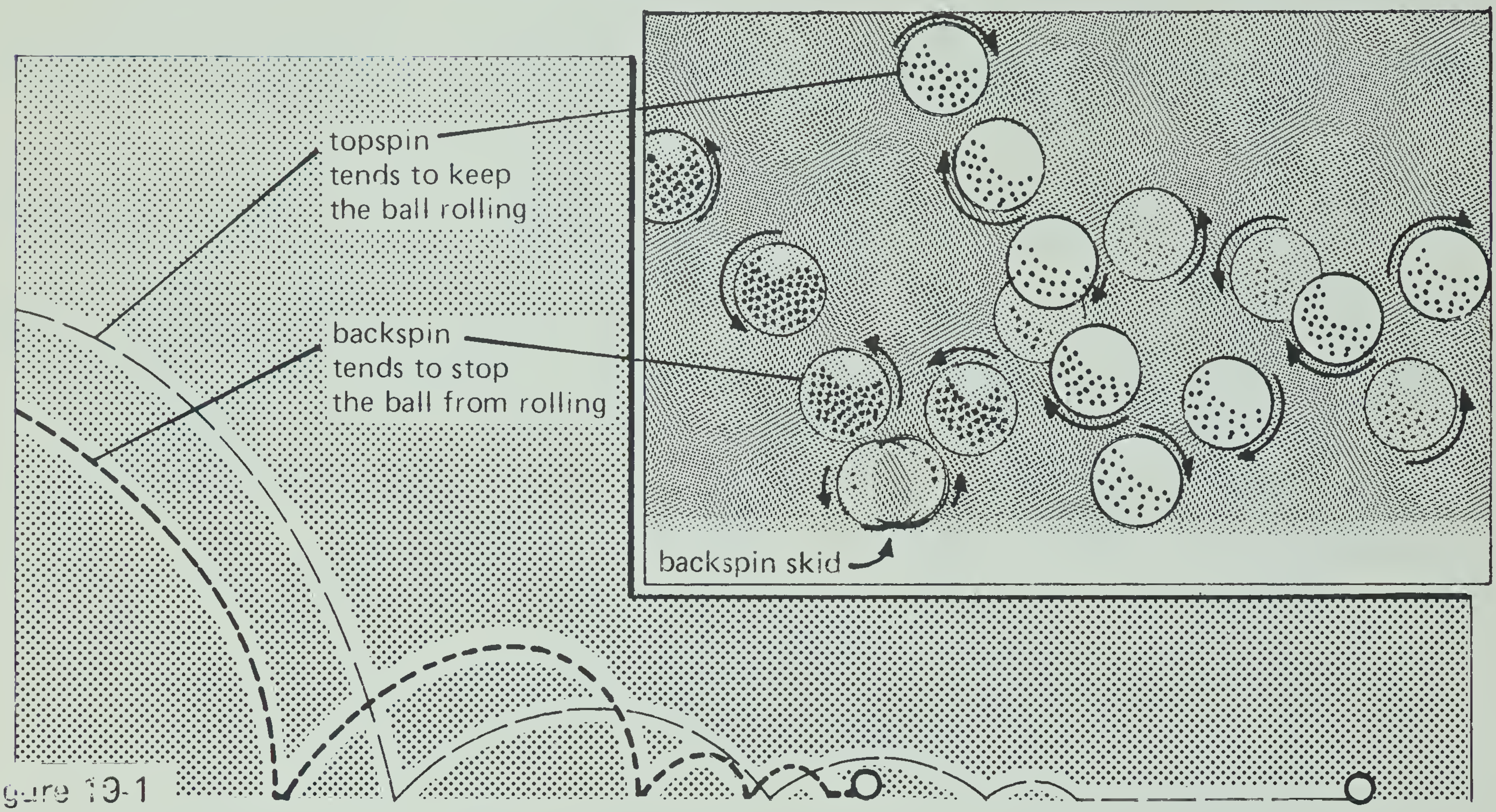


Figure 19-1

19-6. The ball spins in opposite directions.

☆ 19-6. How are topspin and backspin different?

19-7. Topspin causes the ball to keep rolling, but backspin tends to stop the ball from rolling.

☆ 19-7. How are the effects of topspin and backspin different?

When a ball lands, the ground pushes on it with a friction force. Because of the angle of impact, the effect of this force is to produce topspin. If the ball already has topspin, then this friction force tends to increase the rolling distance and lower the height of bounces. The ball scoots along, hugging the ground.

On the other hand, if the ball has backspin, the friction force will be applied in opposition to the direction of spin. The ball will skid and hop as it lands. Depending on which force is stronger, the ball may be merely slowed in its rolling, stopped altogether, or even made to reverse itself — rolling back towards the golfer who hit it.

A professional golfer's wedge shots may draw back several feet on a soft green.

Finally, a ball with sidespin curves in the direction of spin while in the air. But on landing, it bounces ("kicks") in the opposite direction.

Here are some ways spin is used in various sports.

SPORT	TOPSPIN	BACKSPIN	SIDESPIN
Golf	more rolling distance, accurate putts	more height on ball, quick stops on green	hold against cross wind, fade or draw around objects
Tennis, table tennis	keeping stroke low and in court, table-tennis slam, tennis offensive lob	drop shot	lateral bounce or "kick"
Baseball, softball	sinker or drop	fastball or riser	curve, slider, screwball
Pool	more roll on cue ball	backing up cue ball	"hugging the cushion," curving, changing angles of rebound
Football			spiral for stability on both passes and kicks
Bowling			hooking into pocket, better split angles
Basketball	some lay-ups, faster bounce-passes	lay-ups and free throws, slower bounce-passes	some lay-ups, angled bounce-passes

☆ **19-8. List the four kinds of spin (not counting the case of no spin) and describe how each kind affects a ball.**

19-8. Topspin: drops in flight, rolls on landing; backspin: appears to rise in flight, skids or stops on landing; right spin: curves right in flight, kicks left on landing; left spin: curves left in flight, kicks right on landing

ACTIVITY 20: REACTION TIME

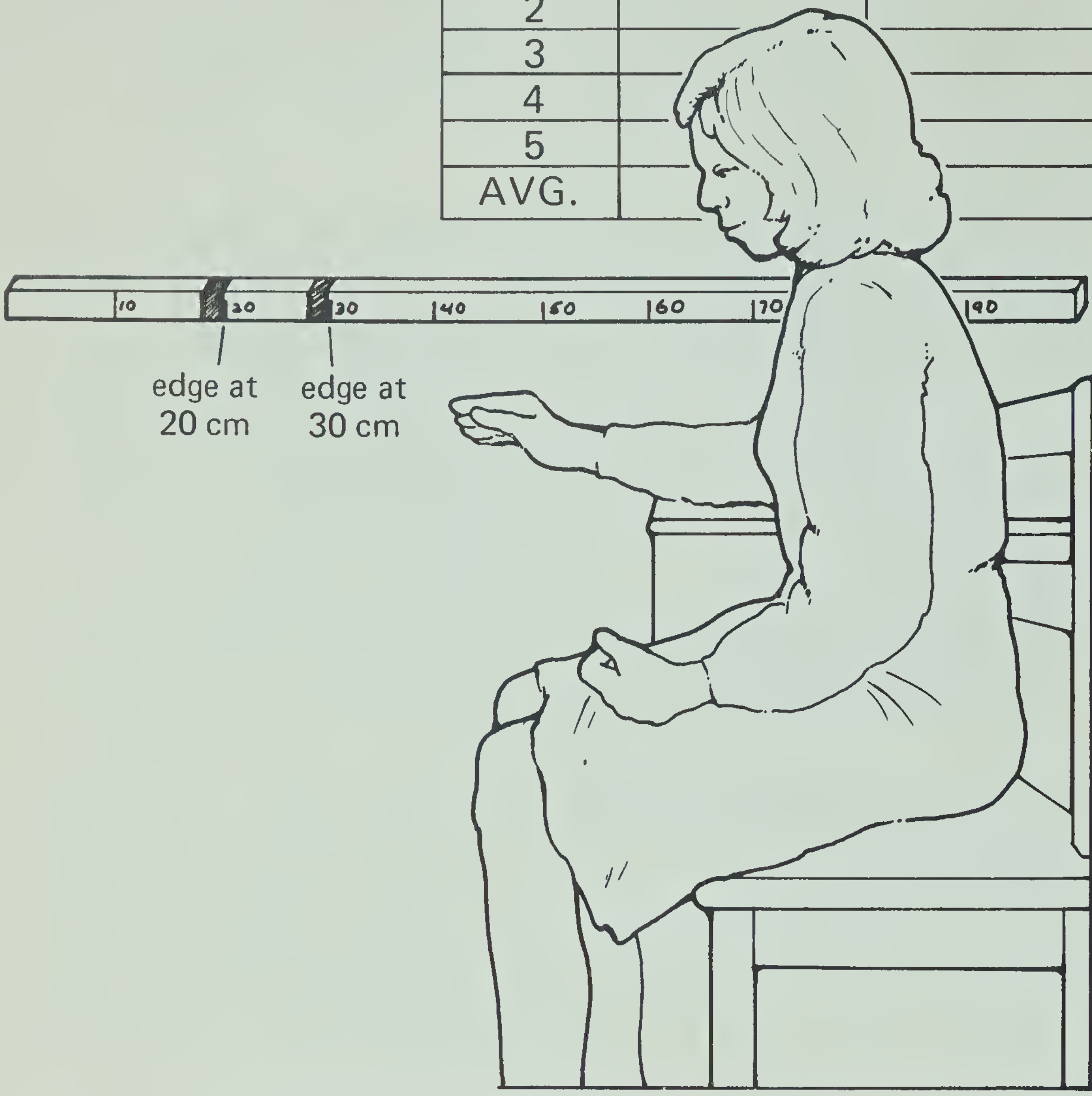
ACTIVITY EMPHASIS: One test of your reaction time can be made by using a metre stick and gravity.

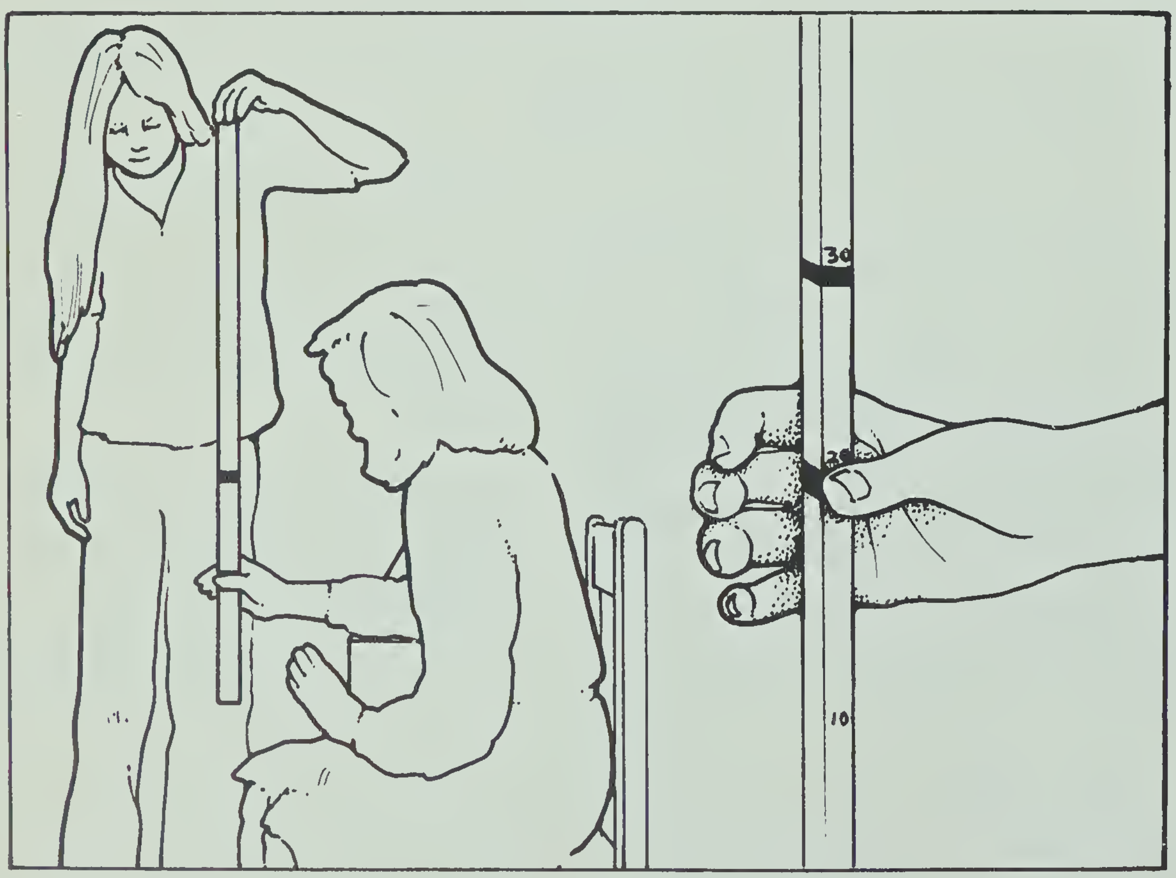
MATERIALS PER STUDENT LAB GROUP: See tables in "Materials and Equipment" in ATE front matter.

There are many activities in sports where success is determined as much by the participant's reaction time as by his muscular skill. In baseball, a home run and a "loud" foul can be separated by a fraction of a second in the timing of the swing of the bat. Here's a standard method being increasingly used to get a measure of a person's reaction time. You will need a partner, fifteen minutes, and the following materials.

metre stick
two small pieces of nontransparent tape

	CATCHING POINT (cm)	
TRIAL	Partner's	Yours
1		
2		
3		
4		
5		
AVG.		





A. Copy this table in your notebook. If you are unsure how to average, look at "Resource Unit 1: Averaging" before going on.

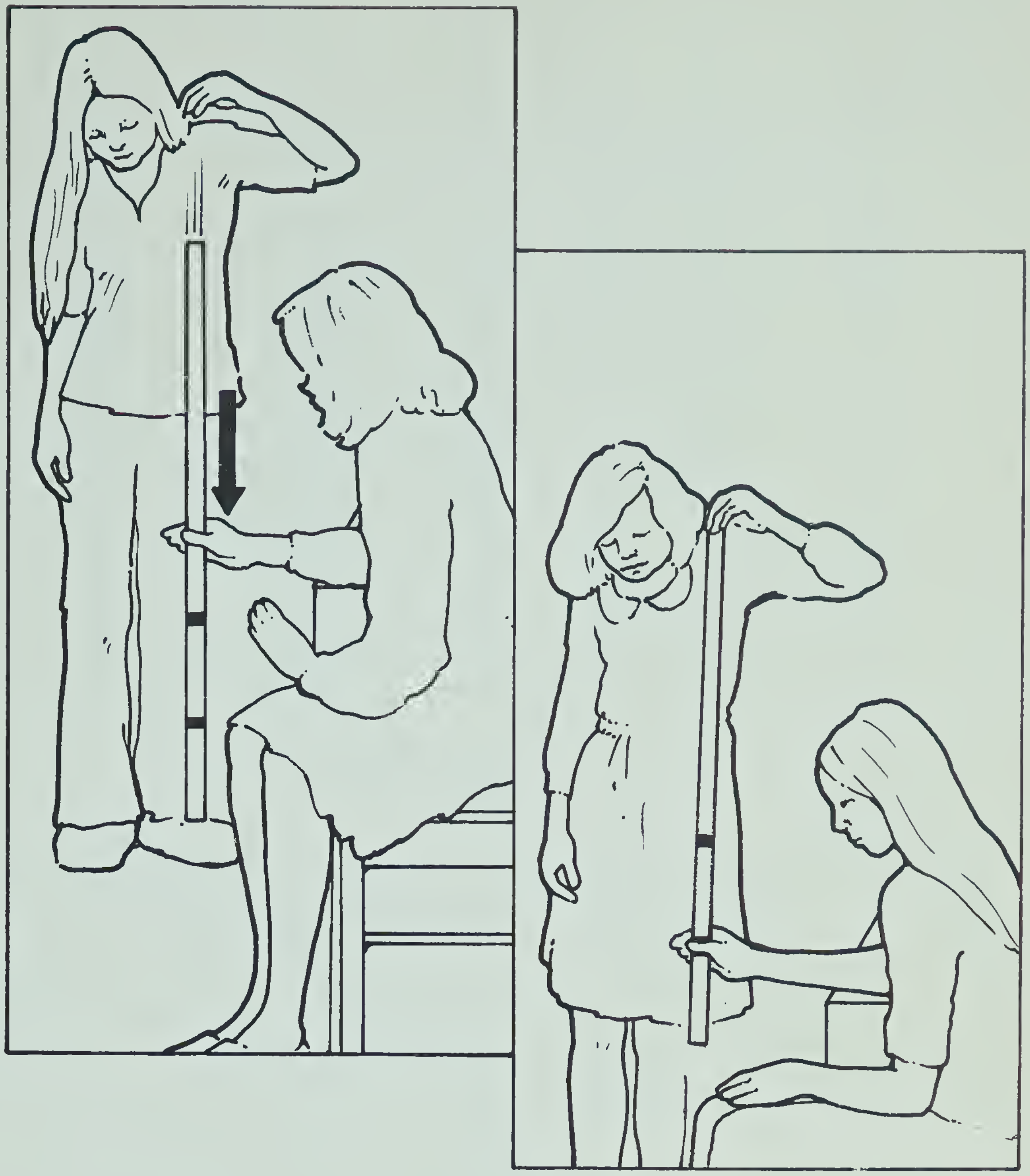
B. Wrap the tape around the metre stick as shown. Line one piece up with the 20-cm mark and line the other piece up with the 30-cm mark.

C. For most people their dominant hand is usually the one they write or throw with. Most commonly this is the right one. Have your partner sit with the dominant hand resting on a desk. Your partner's arm should extend beyond the desk from a point halfway between the wrist and elbow, as shown.

D. Hold the metre stick at the upper end (100 cm) with one steady hand. Let it dangle between your partner's slightly separated thumb and forefinger, as shown. Your partner should not be touching the stick at this time. Line up the 20-cm mark on the stick so that it is level with the top of your partner's thumb.

E. Instruct your partner to concentrate on the 30-cm-tape mark. As soon as the stick begins falling, your partner is to try to snap the thumb and forefinger closed on that (30-cm) mark.

F. Release the stick without warning. Tell your partner to "freeze" with the thumb and forefinger grasping the metre stick. In the table prepared in Step A, enter the exact centimetre number that is now in line with the upper edge of your partner's thumb. Repeat the procedure for a total of five trials. Then get an average.



G. Switch places with your partner in order to measure your own reaction time. Again, do five trials and average them.

• 20-1. Who has the quicker reaction time — you or your parner? How can you tell?

20-1. The one whose average cm measurement was lower. This is because the quicker your reaction time, the fewer cm of the metre stick will have slipped through your fingers.

You really didn't measure reaction *time*. You measured reaction *distance*. So you might have had a little trouble answering the last question. But you can get the speed of reaction in terms of time rather than distance. All you have to do is use the table in Figure 20-1 on page 84. No stopwatch is needed. You just need to know the average number of cm that you allowed the metre stick to fall. Since you started each trial with your thumb and forefinger on the 20-cm mark, the actual number of cm that the stick fell each time will be 20 cm less than the figure you have recorded.

So the first thing to do is to subtract 20 cm from the averaged figure in your notebook. Then look up this new number in the table in Figure 20-1 (page 84). Because distance of fall and time of fall are related, the time of fall is listed right beside the distance number.

DISTANCE OF FALL (cm)	TIME OF FALL (s)	DISTANCE OF FALL (cm)	TIME OF FALL (s)	DISTANCE OF FALL (cm)	TIME OF FALL (s)	DISTANCE OF FALL (cm)	TIME OF FALL (s)
1	0.045	16	0.181	31	0.252	46	0.306
2	0.064	17	0.186	32	0.256	47	0.310
3	0.078	18	0.192	33	0.259	48	0.313
4	0.090	19	0.197	34	0.263	49	0.316
5	0.101	20	0.202	35	0.267	50	0.319
6	0.110	21	0.207	36	0.271	51	0.322
7	0.120	22	0.212	37	0.275	52	0.326
8	0.128	23	0.217	38	0.279	53	0.329
9	0.136	24	0.221	39	0.282	54	0.332
10	0.143	25	0.226	40	0.286	55	0.335
11	0.150	26	0.230	41	0.289	56	0.338
12	0.157	27	0.235	42	0.293	57	0.341
13	0.163	28	0.239	43	0.296	58	0.344
14	0.169	29	0.243	44	0.300	59	0.346
15	0.175	30	0.247	45	0.303	60	0.349

Figure 20-1

Times in the table have been "rounded off," which means that twice the time may not come out exactly to the number it would seem to. For instance, for a distance of 6 cm, time of fall is 0.110 s; for a distance four times as great (24 cm), time is shown as 0.221 s, off by 0.001 s from twice 0.110.

Suppose, for example, that your average distance was 37 cm. You first subtract 20 cm. This gives you 17 cm. Then look up 17 cm in the table in Figure 20-1 above. The time value next to it is 0.186 s. That is your average reaction time.

This table works for any object being dropped. All objects take the same time to fall a given distance (ignoring air resistance). The time of fall is directly proportional to the *square root* of the distance of fall. (The square root of a number is another number which, multiplied by itself, gives the number.) So, for example, for an object to fall four times the distance will take twice the time ($\sqrt{4} = 2$). Check this in the table.

20-2. 0.101 s; 0.202 s

• 20-2. What is the fall time for a distance of 5 cm? What is twice this time?

20-3. 20 cm; 0.202 s

• 20-3. What is four times the distance of 5 cm? From the table, how long does it take to fall this greater distance?

20-4. 1.808 s ($\sqrt{16} = 4$, and 4 times 0.452 = 1.808)

• 20-4. If an object takes 0.452 s to fall 1 m, how long will the object take to fall 16 m?

20-5. The time it takes to fall 5 cm is 0.101 s. $\sqrt{9} = 3$, so the time we might expect is 3 times 0.101 s, or 0.303 s.

9 X 5 cm = 45 cm. From chart, time to fall 45 cm = 0.303 s, Q.E.D.

☆ **20-5. Starting with a distance of fall of 5 cm, demonstrate that to fall nine times as far will take the square root of nine times as long.**

DEFGHIJ 08543
PRINTED IN THE UNITED STATES OF AMERICA

DATE DUE SLIP

SEP 28 '91	
SEP 28 1991 RETURN	

F255

The ISIS Project is an intricate effort involving many people in many roles. The following individuals have made significant contributions to that effort.

ISIS Permanent Staff

Ernest Burkman, Director (1972-)
William R. Snyder, Associate Director (1974-)

Jack J. Bulloff (1977-)
Ace Carroll (1975-)
Maxwell Caskie (1976-)
Robert Celander (1976-)
Richard Chittenden (1976-)
Jerome L. Ciesla (1973-)
Robert L. Cocanougher (1972-)
Sylvia D. Collins (1977-)
Stewart P. Darrow (1973-)
Cheval Fagan (1976-)
Gene Floersch (1975-)
Gail M. Grandy (1973-)
James P. Hale (1974-)
James A. Hathway (1973-)
Jeanne C. Klinzing (1976-)
John R. Knudstrup (1976-)
Ronald C. Laugen (1973-)
Robert C. Loser (1976-)
Adrian D. Lovell (1972-)
Elisabeth McCurnin (1976-)
Dawn McQueen (1975-)
Marvin D. Patterson (1973-)
Charles E. Peters (1973-)
Ronald J. Polland (1976-)
John Roberge (1976-)
Dee Dee Shand (1974-)
Lois S. Wilson (1973-)
Brenda Zeh (1977-)

Former Staff

Tedd Arnold, Gary K. Baker, Denis Blakeway, Calvin E. Bolin, Drennen A. Browne, Robert Buchanan, Marcia Bujold, David L. Camp, Gwendie Camp, Clifton Bob Clark, Sara P. Craig, Julia Damon, Allan D. Dawson, Joel Dawson, Ronald N. Giese, James A. Greenwood, Fred Hartford, Lila T. Kirschbaum, Michael Krone, Francis X. Lawlor, Clarke G. Lieffers, Pam Little, Bernadette R. Menhusen, Brenda Musgrave-Popst, Gerald Neufeld, Hugh Nicholson, Barney Parker, David D. Redfield, Susan Reichman, George A. Reid, Jr., Beverly Smith, Donald A. Smith, John A. Sumner, Clifford Swartz, Jenne Taylor, Mike Tillmans, Ralph G. Vedros, Robert Vickery, Brian Webber, Jay A. Young

Writing Conference Participants and Author Consultants

Betsy Balzano, SUNY at Brockport; David Berey, Roslyn (NY) Schools; Robert Bernoff, Penn. State University; Capt. George Bond, Naval Coastal Systems Laboratory; Ted Bredderman, Delmar, New York; John Cunningham, Keene State College; James DeRose, Marple-Newton (PA) School District; Robert D. Eddy, Tufts University; I. Dwaine Eubanks, Oklahoma State University; Roy Gallant, Rangeley, Maine; Orrin Gould, University of Illinois; Francis U. Hackley, Leon (FL) Schools; Jack Hassard, Georgia State University; Robert E. Horvat, SUNY at Buffalo; Stuart J. Inglis, Medford (OR) School District; Jane Kahle, Purdue University; Al Kaskel, Evanston (IL) Schools; David Klasson, Fall River (CA) Joint Unified School District; David Kuhn, Tarrytown (NY) Schools; Clarence T. Lange, Clayton (MO) Schools; Sander Latts, University of Minnesota; Robert L. Lehrman, Roslyn (NY) Schools; Harleen McAda, University of California at Santa Barbara; Wendell Mohling, Shawnee Mission (KS) Schools; Floyd Monaghan, Michigan State University; Rod O'Connor, Texas A & M University; M. Larry Peck, Texas A & M University; Shirley Richardson, San Diego (CA) Schools; Guenter Schwarz (Deceased); Douglas P. Smith, Florida State University; Claude A. Welch, Macalester College; Owen York, Kenyon College

PHYSICS OF SPORT

ANNOTATED TEACHERS EDITION

Ginn and Company

0-663-37867-2